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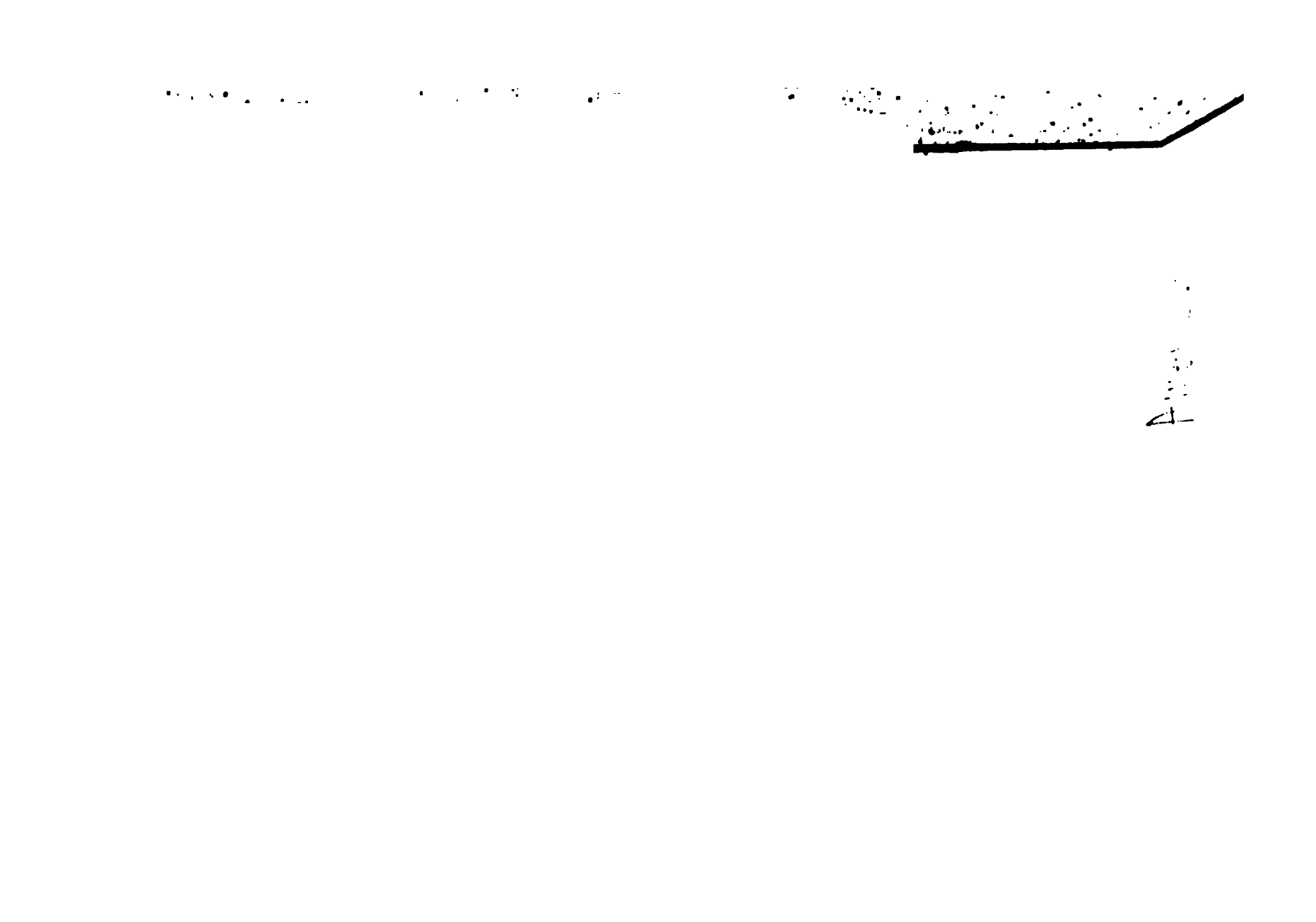

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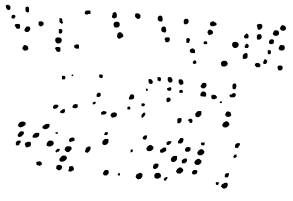

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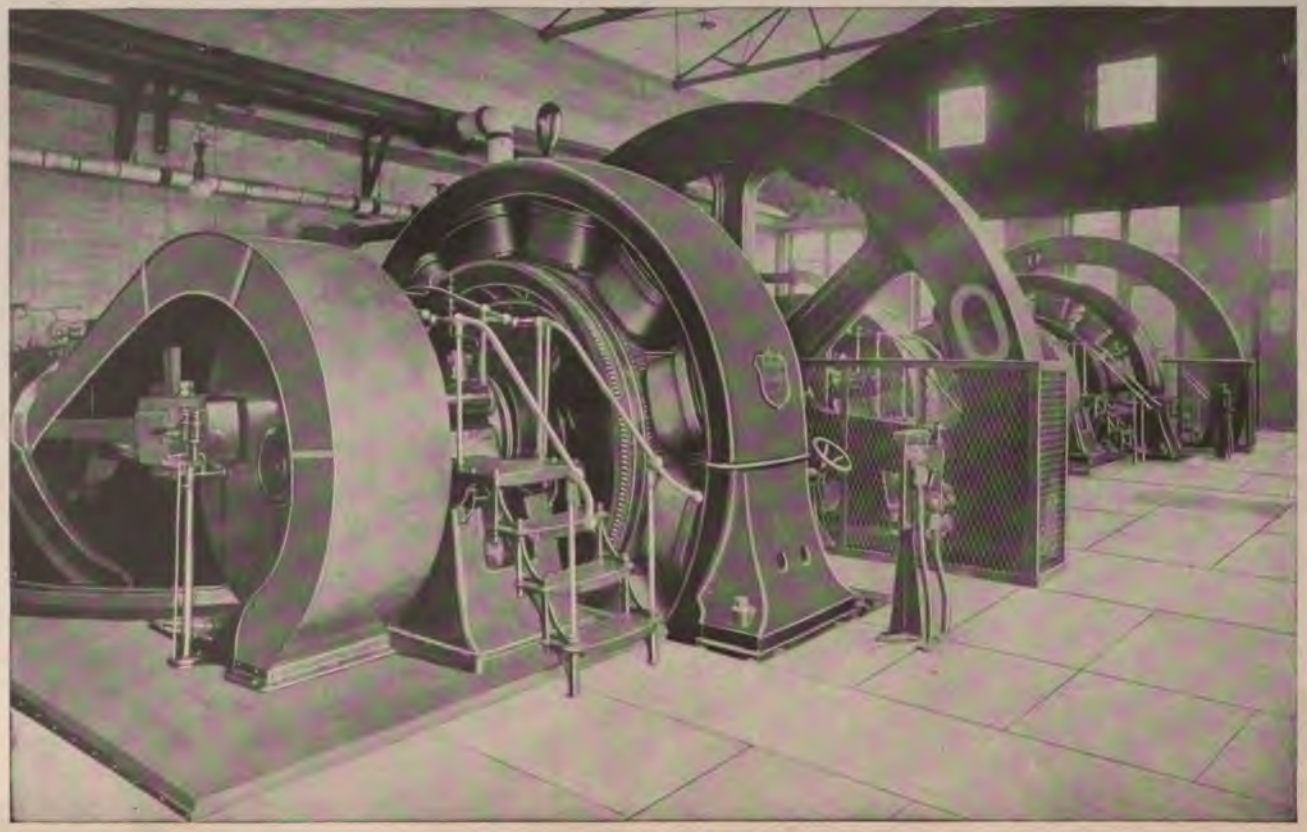

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THEORY OF DYNAMO-ELECTRIC MACHINERY.

THEORY OF THE GENERATOR.

Definition. A dynamo-electric machine is a machine in which mechanical energy is converted into electrical energy, or *vice versa*, by means of electro-magnetic induction.

The term *generator* is commonly applied to a machine which converts mechanical energy into electrical energy.

A *motor* serves to convert electrical energy into mechanical energy. The generator and motor are similar in construction, but the operation of one is the reverse of the other. The motor is separately considered in a following Instruction Paper.

The operation of a dynamo-electric machine depends upon the relation existing between magnetism and the electric current, and the fundamental principles will now be considered.

FUNDAMENTAL PRINCIPLES.

The Magnetic Field. The space surrounding a magnet is subject to its influence, and is called its magnetic field. This influence is exerted in certain definite directions, and its strength and direction are represented by lines of magnetic force. The strength of the field is indicated by the number of magnetic lines per unit area, and is called its density, or magnetic induction.

Fig. 1 represents the field of a permanent magnet, the lines of force passing outside the magnet from the north to the south pole in curved paths. The number of lines per unit of cross-section, and therefore the strength of the magnet, is greatest at the poles.

Magnetic Field of a Conducting Wire. Whenever a current of electricity passes through a conducting wire, the current creates a magnetic field, which surrounds the wire, as shown in Fig. 2. The magnetic lines of this field encircle the wire and have their greatest density near the same, gradually decreasing in effective strength as the distance from the wire increases. These magnetic lines of force represent a form of energy; and, in fact, a considerable

portion of the energy of the current lies in the surrounding magnetic field.

The direction of the magnetic lines about the conductor always bears a definite relation to that of the current. When looking along the wire in the direction of the current, the direc-

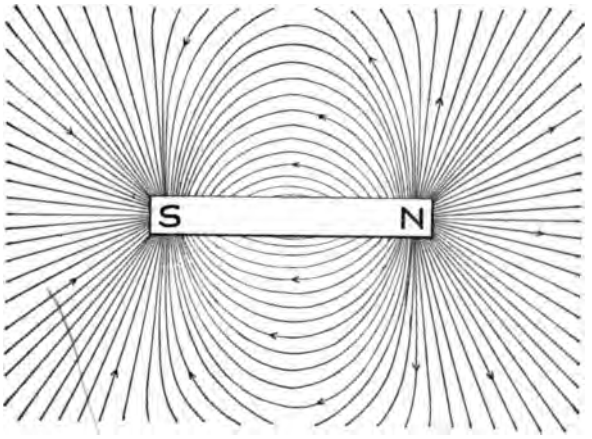

Fig. 1.

tion of the lines of force will always be right-handed; that is, looking at the left-hand end of the conductor shown in Fig. 2, the current being from left to right, the lines of force have the same direction as the hands of a watch.

Field of a Solenoid and Electro-magnet. When a conductor is made in the form of a coil, and a current passed through the same, the lines of force, which would otherwise encircle each turn of the conductor, unite and form a strong magnetic field similar to that of a magnet.

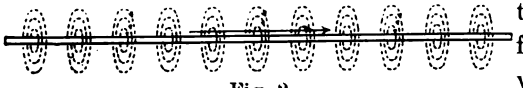

Fig. 2.

The magnetic field of a solenoid is represented by Fig. 3.

When the coil is supplied with a core of soft iron, the effective strength of the magnetic field is greatly increased. Such a combination is called an electro-magnet, and has the properties of a permanent magnet.

The end at which the lines of force leave the iron core and coil is called the north pole, and the end at which the lines enter the

iron core and coil is called the south pole. When a person is facing the south pole, the direction of current in the coil is always in the same direction as the hands of a watch; and when facing the north pole, the current is in the opposite direction to the hands of a watch. This gives a very simple rule for determining the

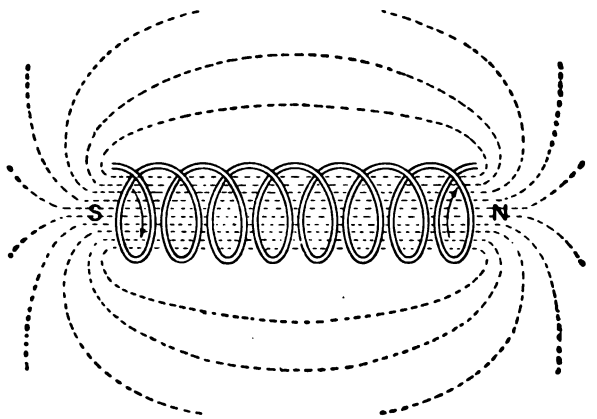

Fig. 8.

relation between the direction of current and polarity of the magnet.

Induced Currents. It would be supposed from the fact that a magnetic field is created by the passage of a current through a conductor, that the reverse action would also take place; that is, the creation of a magnetic field about a conductor would cause the production of a current, and such is found to be the case. The currents created in this manner are called *induced* currents, and are said to be produced by *induction*.

The subject of production of currents by induction is briefly considered in "Elements of Electricity," and the student will note the following facts:

1st. It is only by certain changes of relation between magnetic field and the conductor that the current is produced.

2nd. The change may be due to an increase or decrease in the strength of field about the conductor, and the current flows only while this change in field strength takes plnce.

3rd. The induced current flows in the opposite direction,

when the field strength is increased to that in which it flows when the field strength is decreased.

4th. The change in field strength may be produced by the movement of a permanent magnet, solenoid or electro-magnet in the neighborhood of the conductor, — the source of the field is immaterial.

5th. Relative movement only is necessary, and hence it is immaterial whether the conductor is moved through the field or the field moved across the conductor.

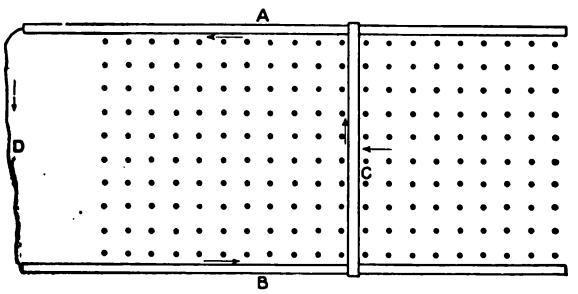

Fig. 4.

6th. The current flows through a closed circuit only as a result of the induced electro-motive force which is first created, and the strength of the current depends upon the value of the induced electro-motive force and resistance of the circuit, in accordance with Ohm's law.

Movement of Conductor Across the Field. We shall now consider more fully the production of E. M. F. and current by movement of a conductor *across* a magnetic field.

In Fig. 4 the dots represent the lines of force of a uniform field, their direction being upward through the paper. *C* represents a conductor which is movable on the rails *A* and *B*, the circuit through *B*, *C* and *A* being completed by the connecting wire *D*. Now when *C* slides along the rails, it cuts across the lines of force, an E. M. F. is induced, and a current flows, as indicated. The movement of *C* across the field causes a difference of potential between its ends, due to the fact that there is a continual cutting of lines of force about the conductor. If the slide *C* were moved endwise, however, no E. M. F. would be generated, as no

lines would be cut, and during such movement there is no relative change of field with reference to the slide. The same would be true if the slide were moved vertically with reference to the paper. The moment there is any *cutting across* of the lines there is an E. M. F. induced. Such induced E. M. F. exists, however, only during the movement of the slide.

Value of Electromotive Force. The magnitude of the E. M. F. generated depends upon the *rate* at which the conductor cuts across the magnetic lines; that is, it depends upon the number of lines cut in a unit of time. If the conductor cuts across the field in a plane perpendicular to the lines of force, as indicated in Fig. 4, the E. M. F. would depend only upon the field area passed over in a unit of time and upon the density of the field. It therefore follows that the rate at which the lines are cut is determined by the *length* of the conductor, its *speed*, and the *strength* of magnetic field.

Taking, for example, the simple conditions of Fig. 4, let L represent the length of slide C, v its velocity, and B the field density, then

E. M. F. *varies as* $L \times v \times B$.

The electric and magnetic units are based upon the metric system, and have been so chosen that when a conductor cuts 100,000,000 lines of force per second, there exists a potential difference between its ends of 1 volt. The unit upon which the volt is based is the potential difference generated by moving a conductor 1 centimeter long at the rate of 1 centimeter per second across a field which has a strength of 1 line per square centimeter. This very small unit would be inconvenient for practical purposes, and so the volt was taken as 100,000,000 times this quantity. Hence it follows that

$$E = \frac{L \times v \times B}{100{,}000{,}000} = \frac{L \times v \times B}{10^8} = L \times v \times B \times 10^{-8}$$

where E = E. M. F. in volts induced in moving conductor:

L = length of conductor in centimeters;

v = velocity in centimeters per second;

B = number of lines of force per square centimeter.

Therefore, having given the length of conductor, the velocity and the field density, the E. M. F. generated may be computed

readily; or if any three of the quantities are given, the fourth may be determined.

Example.— A conductor .6 meter long cuts across a uniform field having a density of 8,000 lines per square centimeter at the rate of 90 meters per minute. What is the voltage generated?

Solution.— Applying the preceding formula, $L = .6 \times 100 =$ 60 cm., $v = \frac{90 \times 100}{60} = 150$ cm., and $B = 8{,}000$.

Substituting these values,

$$E = 60 \times 150 \times 8{,}000 \times 10^{-8} = .72 \text{ volt.}$$

Ans. .72 volt.

Example.— In order to generate a voltage of 1.1 by a conductor 1 meter long, when moving across a uniform field at the rate of 108 meters per minute, what must be the magnetic induction?

Solution.— The known quantities are

$$E = 1.1,\ L = 1 \times 100 = 100,\ v = \frac{108 \times 100}{60} = 180.$$

Substituting these values,

$$1.1 = 100 \times 180 \times B \times 10^{-8}$$

Or,
$$B = \frac{1.1 \times 100{,}000{,}000.}{18{,}000}$$

$$= 6{,}111+$$

Ans. 6,111 + lines.

Direction of Induced Current. There is a definite relation between the direction of induced E. M. F., or current, the direction of motion and the direction of the lines of force. Referring to Fig. 4, and remembering that the lines of force are assumed to pass upward through the paper, and the slide C to move to the left, the direction of current along C will be that indicated by the arrow. The direction of lines of force, motion and current are all at right angles to each other. If C were moved to the right instead of to the left, the current would flow in the opposite direction to that indicated.

A simple rule for determining the direction of current is the "finger-rule" of Dr. Fleming. This is illustrated in Fig. 5. When the first three fingers of the *right* hand are placed so that they are at right angles to one another, then if the forefinger is

pointed in the direction of the lines of force and the thumb in the direction of motion, the middle finger will indicate the direction of induced E. M. F., or current.

For example, if the lines of force were horizontal and passed from left to right and the conductor moved upward in a vertical plane across the lines, the direction of current in the conductor would be away from the observer. Also, if the direction of the lines of force of Fig. 4 were downward through the paper and the slide *C* were moved to the right, the current would still be in the same direction as that indicated. That is, if the direction of both the field and of motion be reversed, then the direction of current remains unchanged. Reversing *either* the field *or* the motion will reverse the direction of current.

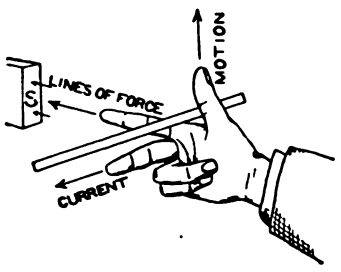

Fig. 5.

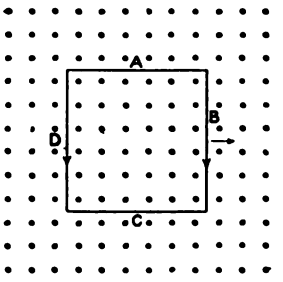

Fig. 6.

E. M. F. in Closed Coil. The E. M. F. is generated in the dynamo-electric machine by movement of coils of wire through a magnetic field. We shall now consider the E. M. F. generated in a closed coil when moved in different ways through a magnetic field.

The dots in Fig. 6 represent a uniform magnetic field passing upward through the paper. *A B C D* represents a closed conducting coil, and let us suppose it is moved to the right, as indicated by the arrow. In such an event, sides *A* and *C* cut no lines of force, and no E. M. F. is generated by them. Side *B*, however, cuts the field, and by applying Fleming's rule it is evident that an E. M. F. is generated in the direction shown by the arrow applied to *B*. Also, as side *D* is subject to the same conditions, an E. M. F. is generated in the same direction as that in *B*, and as each cut the same number of lines of force in

the same time, the E. M. F.'s generated are equal. Sides *A* and *C*, although not effective in cutting the field, serve as connecting conductors for the other sides. It is clear from the figure that the E. M. F.'s in *B* and *D* oppose each other, and therefore no current flows. In a similar manner it may be shown that no current will flow, no matter how the coil is moved, provided it always lies in a plane perpendicular to the magnetic lines. The E. M. F. generated in one part of the coil will always be opposed by an equal and opposite E. M. F. generated in the remaining part.

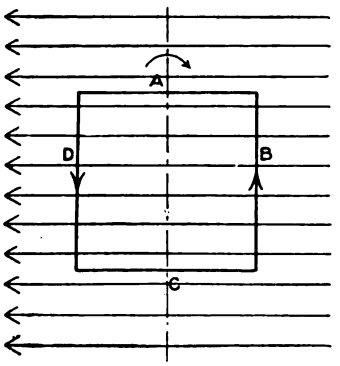

Fig. 7.

When, however, the coil is turned about an axis, the result is different. This may be understood by considering Fig. 7. Here the magnetic lines are represented as passing from right to left, and the coil as being turned about an axis in the direction indicated. The sides *A* and *C* cut no lines of force, and therefore generate no E. M. F. For the position shown, side *B* is moving downward through the paper and cuts directly across the lines and generates an E. M. F. in the direction indicated. Side *D* is moving upward, and therefore generates an E. M. F. in an opposite direction to that in *B*. These two E. M. F.'s, therefore, act in the same direction through the coil, and a current flows; the full E. M. F. of the coil being the sum of that generated by each side. This applies to every position of the coil as it rotates about its axis.

While the coil rotates, the number of magnetic lines passing through it is constantly changing, being a maximum when at right angles to the lines, and being zero when parallel to the lines, as in the position shown in Fig. 7. On the other hand, for the movements referred to when considering Fig. 6, the same number of lines passes through the coil at all times, and it may be stated as a general rule, that an E. M. F. is generated in a closed circuit when the same is moved so that the number of magnetic lines passing through it is altered during the motion.

APPLICATION OF PRINCIPLES TO DYNAMO-ELECTRIC MACHINES.

As an E. M. F. is induced in a conductor only while it moves through a magnetic field, thus cutting the lines, it is necessary for the production of a continuous current to have conductors arranged and interconnected so that some are always effectively cutting the field. This result is attained in the generator by rotating such conductors between the north and south poles of a magnet. We shall first consider a single conductor so rotated.

E. M. F. Induced by Rotating Single Conductor. In Fig. 8 suppose a conductor perpendicular to the paper to revolve with a uniform motion on the dotted circle between the *N S* poles, the field having a uniform density. The right-hand portion of the figure will then represent graphically the varying values of the induced E. M. F., and is called the curve of induced E. M. F.

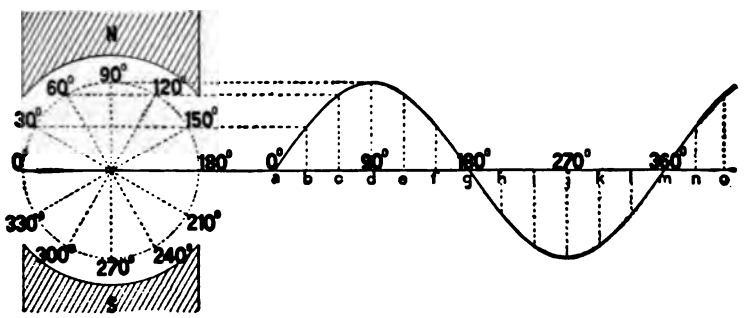

Fig. 8.

The horizontal line is divided into equal parts at points *a*, *b*, *c*, etc., and represent intervals of 30° in the rotation of the conductor. That is, the distance to the curve above or below the line at any point *a*, *b*, *c*, etc., represents the value of induced E. M. F. for the corresponding position of the conductor. For example, when the conductor is at the position 0°, it is then moving *parallel* with the lines of force, and no E. M. F. will be induced. Hence for 0° at *a* the value is represented as zero, which forms the starting-point for the curve. When the conductor has travelled 90° and is opposite the middle of pole *N*, it is cutting directly across the field, and at this time generates the maximum E. M. F. The

curve is therefore at its highest point above *d*. At the intermediate points 30° and 60° between 0° and 90° the E. M. F. gradually increases as represented at *b* and *c*. As the conductor continues to revolve, a less and less number of lines are cut, until at 180° it is again moving parallel with the lines, and no E. M. F. is induced. This condition is represented at *g* where the curve crosses the line. At intermediate points between 90° and 180° the E. M. F. has a gradually decreasing value. After passing the 180° position the conductor again begins to cut a gradually increasing number of lines, but now cuts across them in the opposite direction to that during the first half of the revolution. The E. M. F. induced will therefore be in the opposite direction. Hence at 210° and 240° the E. M. F. gradually increases in an opposite direction, as shown at *h* and *i*. At 270° the maximum E. M. F. is being generated in the reversed direction, as represented at *j*. Upon completion of the 360° of one revolution, the E. M. F. again becomes zero. By continuing the rotation of the conductor the above series of changes will be repeated during each revolution. Hence during each revolution the induced E. M. F. rises from zero to a maximum, decreases, reverses, rises to a maximum in the opposite direction, and decreases to zero again.

Simple Form of Alternating Current Generator. We have seen that when a coil is rotated in a magnetic field, the opposite sides aid each other and the E. M. F. is double that produced by a single conductor. By the use of such an arrangement of a coil a simple form of alternating current machine is created. Fig. 9 represents the arrangement. The coil is mounted so as to rotate between the north and south poles of a magnet. The ends of the coil are connected to copper *collecting rings R R*, mounted on the shaft with the coil but insulated from each other. Upon each ring presses a stationary *brush B*, which is always in contact therewith, and serves to conduct the current to an outside circuit *W*. A complete circuit is then made up from one brush through the external wire *W* to the other brush, then to its collecting ring, through the coil to the other collecting ring, and to the first brush again. The alternating current produced by the rotation of the coil will then pass to the external circuit through the collecting rings and brushes, and during one-half of a revolution the current

will pass in one direction and during the remaining half in the opposite direction. The current in the external circuit is available for doing work, and may be passed through motors, lamps, heating appliances, etc.

The Commutator. For the purpose of producing a direct current from the alternating current induced by a rotating coil, a device called a *commutator* is necessary. Its simplest form is shown in Fig. 10, and consists of a split copper ring, the two *segments* of which are insulated from each other, and each segment is secured to one end of the rotating coil. Although an alternating E. M. F. is induced in the coil, by the use of the commutator the current in the external circuit is always in the same direction. This may be understood from Fig. 10.

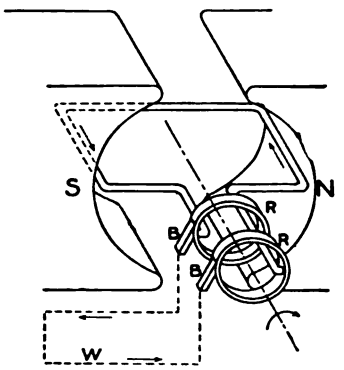

Fig. 9.

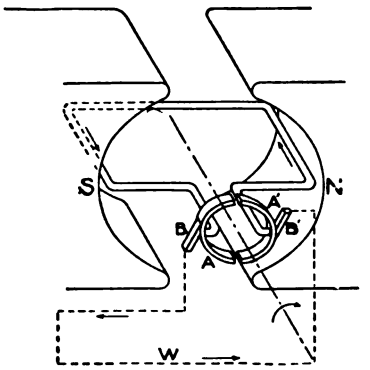

Fig. 10.

For the position of the coil shown, its current will be in the direction indicated and will pass to segment A, brush B, through the external circuit to brush B' and segment A' to the coil. As the coil continues to rotate, the E. M. F. gradually decreases, until when 90° from the position shown, the E. M. F. is zero. At this time the segments are located so that the brushes are about to break contact with one segment and make contact with the other. Further rotation induces an E. M. F. in the opposite direction, but the segments have then passed from one brush to the other, and the direction of current in the external circuit therefore remains unchanged. That is, when the current in the coil is in the direction indicated, segment A will *deliver* current to brush B,

but when in the opposite direction segment *A* will be under brush *B'* and *receive* current from it. The commutator therefore serves to change the direction of the alternating current in the coil to a direct current in the external circuit.

Form of Curve. The curve of induced E. M. F. in the external circuit when a two-part commutator is used is shown in Fig. 11, and is the same as that in Fig. 8, except that the negative portion of the curve is turned above the horizontal. The direction of the current is always the same, but rises to a maximum and falls to zero twice during each revolution, giving what is called a *pulsating* current. It must be remembered, however, that the form of curve shown is the theoretical curve, with the assumption that the speed is constant and the field density uniform. With the actual machine, of course, the conditions are modified more or less, and other considerations, such as self-induction and distortion of the field, materially alter the form of the curve.

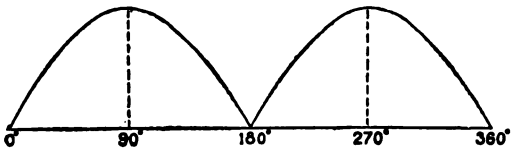

Fig. 11.

The coil, instead of consisting of a single turn, may be made up of two or more, as shown in Fig. 12. The sum of the electromotive forces induced in each turn is the resultant E. M. F. of the coil. Hence if there are n turns, the resultant E. M. F. will be n times the E. M. F. induced in one turn.

Owing to the fact that a pulsating current is generally undesirable for practical work a two-part commutator is now seldom used. The current is rendered nearly constant in value, however, by the use of several coils and a commutator made up of a corresponding number of segments. The coils are interconnected so that the E. M. F. induced in each is added to that of the others. The various methods of connecting will be considered on following pages, and only the principle will now be considered.

Suppose we have two coils at right angles to each other revolving in a magnetic field, and connected in such manner as to assist each other and yield a direct current to the external circuit. Then, while the maximum E. M. F. is induced in one coil, no

E. M. F. will be induced in the other, and at intermediate points there will be gradual changes. In Fig. 13 the dotted lines indicate the E. M. F.'s induced separately in the two coils, one being 90° in advance of the other. The combining of the two curves produces the curve in full lines, which is formed by taking the sum of the dotted curves. The upper curve therefore represents the fluctuation in E. M. F. of the combined coils, and it is evident that the amount of fluctuation is greatly reduced. In a similar manner it may be shown that a further increase in the number of coils, spaced uniformly, will cause less and less fluctuation, and by using 30 or more coils, a practically constant current may be obtained.

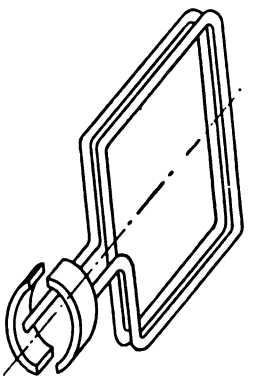

Fig. 12.

Parts of the Generator. Fig. 14 illustrates the essential elements of a generator, which consist of two principal parts,—the stationary *field magnets* and the *armature* which revolves between the poles. A current is passed through the winding around the *cores F F*, to produce the magnetic field in which the

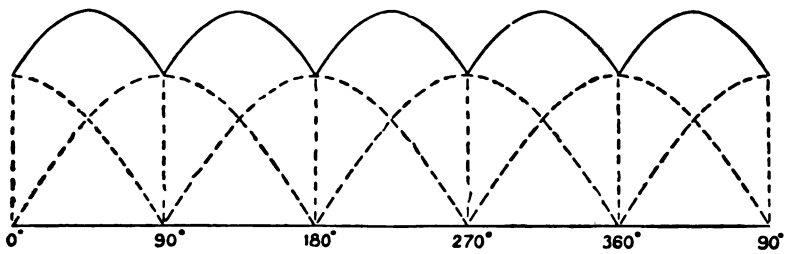

Fig. 13.

coils may rotate. A path for the magnetic lines is provided by the iron cores *F F*, the *yoke Y*, the pole pieces *N S* and the armature as indicated by dotted lines. The armature is made up of the coils and a soft iron core which serves to conduct the magnetic lines. All the coils are interconnected by means of the *commutator C*. The brushes *B B* press lightly upon the commutator and condnct the current to the external circuit, as has been pre-

viously explained. The brushes are made adjustable and are carried by *brush-holders* on a *rocker* or *ring* provided for the purpose.

Frequently, and in all large machines, more than two poles are used. Fig. 15 illustrates the magnetic circuit of a dynamo with four poles. Machines having two poles are called bipolar machines, while those with more than two poles are called multipolar. Some machines have as many as 32 poles. The magnetic circuit is always of such form and construction as to produce a strong field in which the armature rotates. For this purpose it is desirable to have the length of the magnetic circuit, or the distance through which the lines of force pass, as short as possible. The material of this circuit is soft iron or soft steel, in order that the field may have great density.

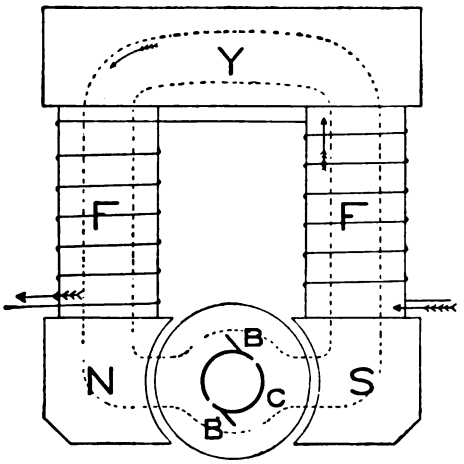

Fig. 14.

Referring to Fig. 14, it will be seen that the magnetic lines pass through the yoke, field cores and pole pieces, then pass across air spaces, called the *air gaps*, and then through the armature core. The armature core is sometimes in the form of a drum and sometimes in the form of a ring, and is always made of very soft sheet iron or soft steel. Since the magnetic lines pass through air with great difficulty compared with the ease of passing through iron, the air gaps are always made as small as mechanical considerations will permit.

The armature is composed of the core above mentioned and the copper coils or windings about the core. The core serves to conduct the magnetic lines from one pole piece to the other; it is mounted upon a supporting frame of cast iron which is firmly secured to the driving shaft and therefore rotates with it. The

shaft is usually supported in self-oiling and self-aligning bearings, and must be constructed so that the armature will always be centered between the pole pieces.

Energy Required to Drive the Dynamo. Although there is no mechanical resistance to the rotation of the armature except friction, the mechanical energy required to drive the armature varies with the amount of electrical energy obtained. When no current is delivered, the armature may be easily rotated; but as soon as a current flows, it reacts upon the magnetic field and opposes the rotation, and the greater the current, the greater the energy necessary to drive the machine. The amount of energy necessary to rotate the armature therefore increases as the load put upon the machine increases.

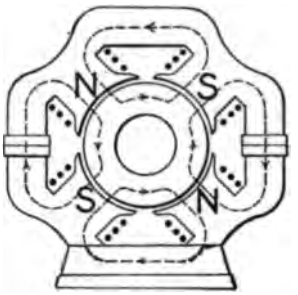

Fig. 15.

ARMATURE WINDINGS.

There are two distinct types of armature windings; one is called the *closed coil* and the other the *open coil* winding.

In the closed coil winding, all the conductors are interconnected so as to form an endless winding, consisting of two or more branches connected in parallel. In the open coil winding the conductors are joined in groups, each group containing in series all conductors which have a similar position with reference to the field. The current is supplied to the external circuit only from those groups which are generating the highest E. M. F.; all other groups being cut out of the circuit temporarily.

Armature windings may also be divided into *ring* and *drum* windings. In the first, the conductors are wound upon and in the form of a ring; in the second they are wound longitudinally upon a cylinder or drum. Open coil windings are used only in special types of machines, such as those for arc lighting; closed coil windings are used in machines for such common purposes as incandescent lamps, power and heating.

Closed Coil Ring Windings. The ring winding is the simplest, and therefore will be first considered.

Figs. 16 and 17 represent a four-coil Gramme or ring winding having a four-part commutator, and consisting of four coils wound about the iron core, with the junction of the coils connected to the commutator bars. The magnetic lines from the north pole pass to the iron core and then to the south pole, as indicated by the dotted lines, there being no magnetic lines across the space enclosed by the ring. Hence as the armature rotates, the conductors on the exterior surface of the ring cut across the magnetic lines twice during each revolution, while the conductors within the ring merely serve to connect the outside conductors in

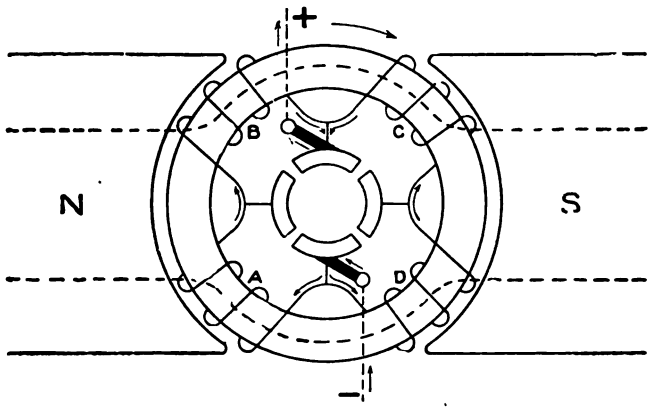

Fig. 16.

series, and are not effective in generating E. M. F. Each coil in Figs. 16 and 17 is made up of three external conductors, and therefore the E. M. F. of each coil will be three times that of a single conductor.

In Fig. 16 coils *A* and *C* are shown as having partly entered the magnetic field, and coils *B* and *D* about to pass out of the field. The path of the current is indicated by the arrows and passes from the external circuit to the lower brush and one bar of the commutator; it then divides and passes through coils *A* and *B* in series on the left, and coils *D* and *C* in series on the right; it then unites, passing to the upper commutator bar and upper brush to the external circuit. As there are two coils in series, the total E. M. F. will be the sum of the E. M. F.'s of the two coils for this position.

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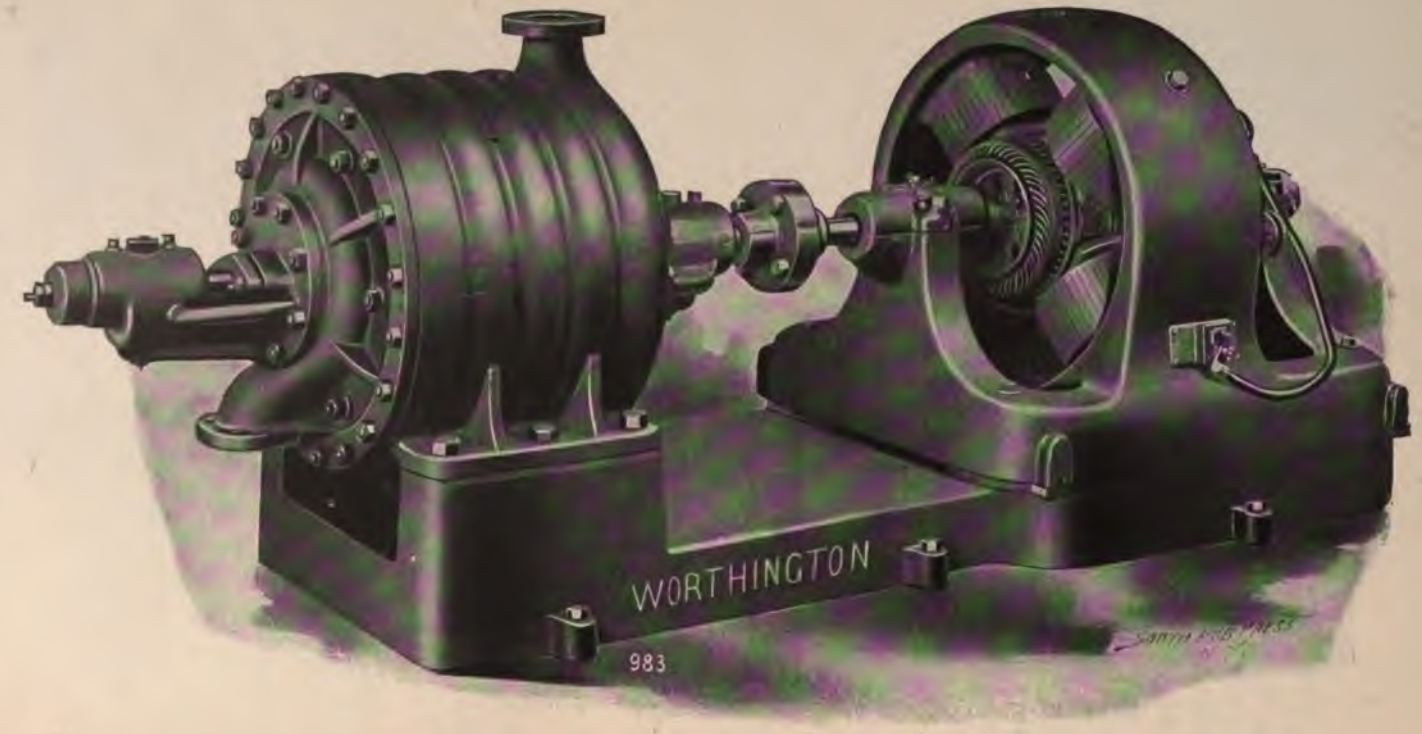


FIVE-STAGE MOTOR-DRIVEN TURBINE PUMP.

Adapted to Heads up to 750 Feet.

Fig. 17 shows the position after the armature has advanced 45° from that shown in Fig. 16. Coils *A* and *C* are then generating the maximum E. M. F., and the current passes from the lower brush through coils *A* and *C* in parallel to the upper brush. Coils *B* and *D* are in what is called the "neutral position," and generate no E. M. F.; in fact, they are temporarily *cut out* of the

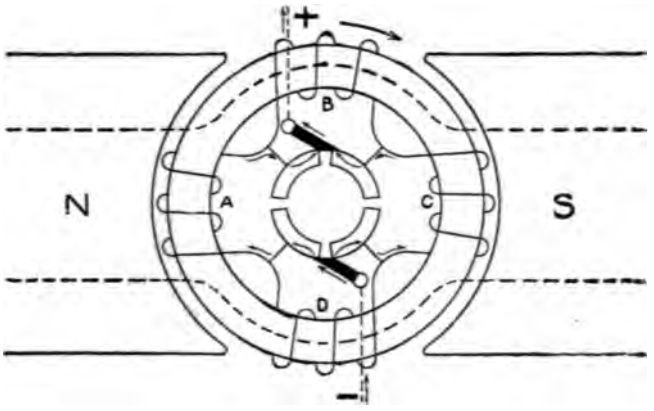


Fig. 17.

circuit, the commutator bars and brushes forming direct connections between coils *A* and *C*. Coils *B* and *D* are said to be *short-circuited;* that is, there is a direct connection of low resistance between the ends of these coils by the commutator bars and brushes, and no current will then pass through the coils.

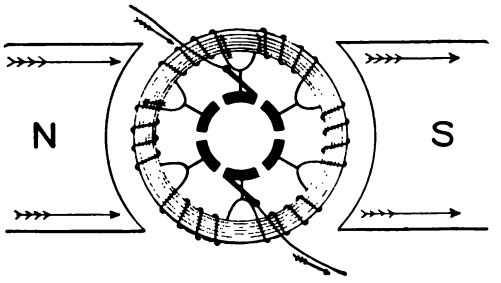


Fig. 18.

Upon further rotation, coils *B* and *D* will pass to the other side of the brushes and they will then generate an E. M. F. in the opposite direction.

Fig. 18 shows a ring-wound armature with six coils and as shown, the current divides, passing through the two halves of the winding in parallel. All the coils on one side are in series, and

each add their portion to the total E. M. F.; the greater the number of coils, the less will be the fluctuation in the current, as explained on page 15. The E. M. F. of each coil varies at different positions, and the E. M. F. generated by some of the coils is increasing, while that of others is decreasing. The total E. M. F., however, remains practically constant when thirty or more coils are used.

Fig. 19 shows a ring winding for a machine with four poles. The winding is the same in form as for a bipolar machine, but the number of brushes and number of circuits through the armature is doubled. Therefore there are two positive brushes and two negative brushes. The two positive brushes are electrically united and connect with the positive wire of the external circuit, while the two negative brushes are united and connect with the negative wire of the external circuit. The current divides at each of the negative brushes, passing in parallel through four circuits (two for each brush) to the positive brushes.

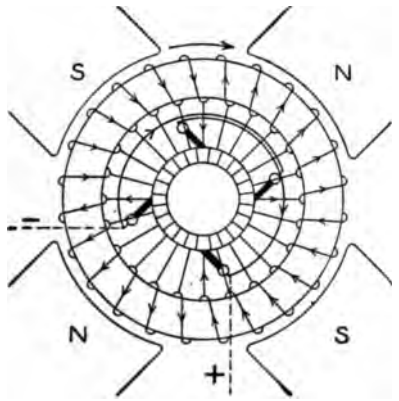


Fig. 19.

For machines with a larger number of poles, there would be a corresponding increase in the number of circuits through the armature.

The number of pairs of brushes may also be correspondingly increased or there may be but one pair since all terminal sections of the same sign (+ or —) can be soldered together.

Closed Coil Drum Windings. Drum windings are distinguished from ring windings in that all wires of the drum armature are distributed over the outside surface of the core. The winding forms a cage which envelops a cylindrical iron core. In the ring armature a large portion of the winding merely serves as connecting leads for that part which lies on the exterior of the core. In the drum armature, however, the only conductors serving as

connectors are at the ends of the cylinder, and therefore a very different form of winding is necessary.

In the ring winding, adjacent conductors are connected directly in series with each other by looping around the ring core, but in the drum winding the return portion of the loop must lie on the exterior of the core, and in order that the E. M. F. induced in each part shall aid the other, the return portion must lie under a pole of opposite polarity to that under which the forward portion lies, as in Figs. 9 and 10.

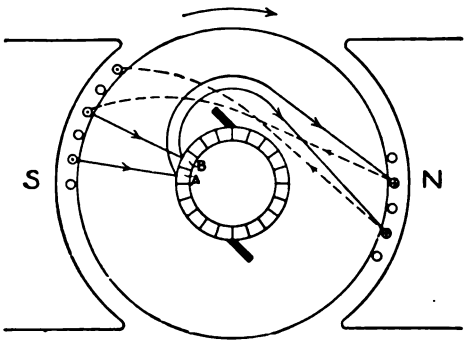


Fig. 20.

The current in passing through the armature from brush to brush must gradually progress through each turn in series. Fig. 20 illustrates a portion of a drum winding, only two complete turns being shown. The small circles represent end views of conductors on the surface of the armature. The crosses and dots indicate the direction of current, the cross representing the tail of a retreating arrow and the dot the head of an approaching arrow. The current gradually progresses from bar to bar of the commutator as indicated by the arrows. The current passes to bar *A* from a conductor at the left of the core, under the influence of the south pole, then by a spiral connector to a conductor under the north pole, thence by a spiral connector at the back end of the core to a conductor under the south pole to bar *B*, then by a spiral connector to a conductor under the north pole, etc. It will be noticed that only the alternate conductors are connected in series, but the intermediate conductors are connected in series with each other to the right-hand half of the commutator.

In order to make all end connectors of the same length and form, the commutator is usually turned 90° in advance of the position shown in Fig. 20, giving an appearance as in Fig. 21. This causes brushes of drum-wound machines to

be opposite the poles instead of between them as in ring-wound machines.

Fig. 22 gives an end view of a complete drum winding in which there are ten complete turns and ten commutator bars. The windings form two circuits in parallel from brush to brush, as may be seen by tracing out the paths of the current. All parts of the winding are similar to each other, and a portion, called an *element*, is made in heavy lines to show clearly the general shape of the turns.

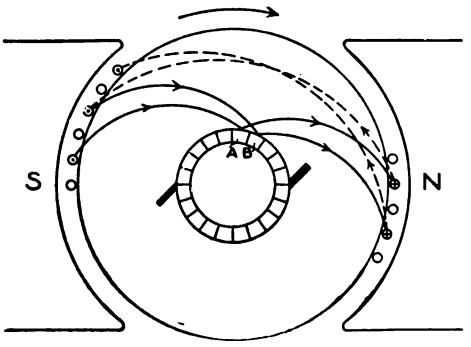


Fig. 21.

Fig. 23 shows a form of drum winding for a four-pole machine with fifteen turns and fifteen commutator bars. It will be seen from the figure that there are four separate circuits between the brushes, two being in parallel from each brush to the other.

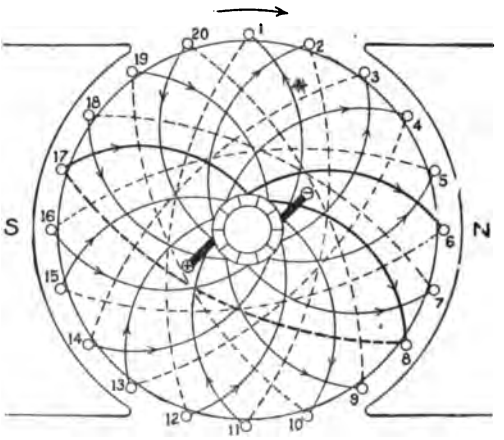


Fig. 22.

Open Coil Windings. Open coil windings are similar to closed coil, except that there are no end connectors between the commutator bars; each coil being alternately cut in and then out of the circuit. Such a winding of four coils with four commutator bars is shown in Fig. 24. The opposite coils are connected in series and each pair of coils alternately make connection with the brushes.

In General. Only the simplest forms of winding of the

different classes have been considered on the preceding pages, and these were illustrated with figures showing a small number of turns. In the actual machine, however, the number of turns is much larger, and there are also a great variety of windings under each type, many of which are equivalent electrically but allow considerable variation in the mechanical construction. The number of

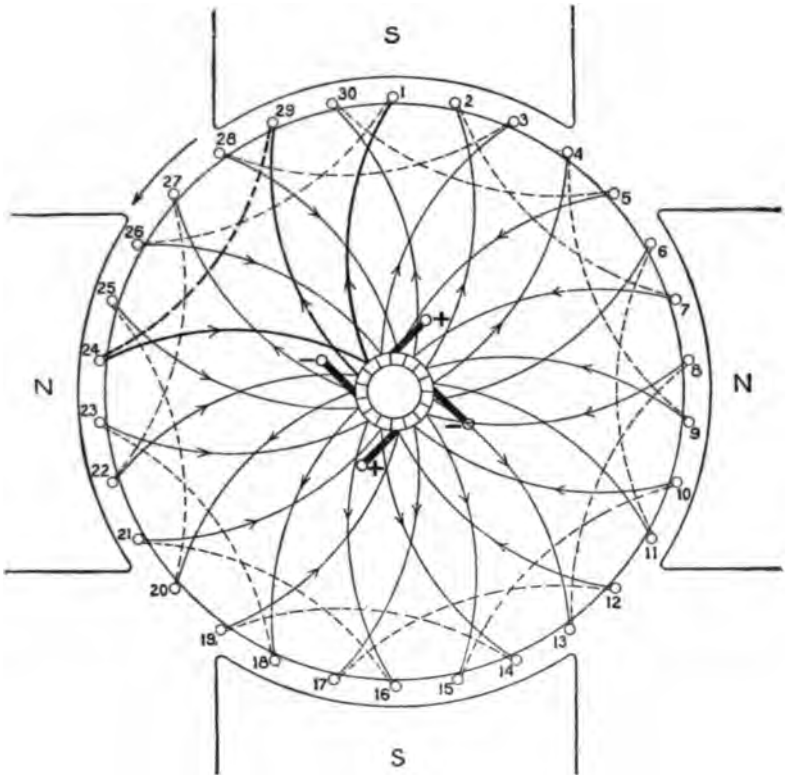


Fig. 23.

poles and the number of brushes used also permit the connecting of the conductors in a variety of ways.

Calculation of E. M. F. Referring to page 7, it is seen that the value of E. M. F. in volts generated by a conductor moving in a uniform field is given by the formula,

$$E = \frac{L \times v \times B}{10^8} = L \times v \times B \times 10^{-8}$$

in which L is the length of the conductor in centimeters, v the velocity in centimeters per second and B the field strength in lines of force per square centimeter.

From the above formula we can arrive at the voltage of the actual machine. By reference to the figures showing armature windings, it appears that a single armature conductor is opposite a pole, and therefore *active* in cutting lines of force only during certain periods of each revolution. The field opposite a pole is practically of uniform strength, and when a conductor is not

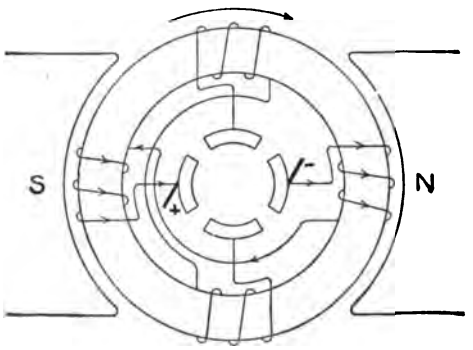


Fig. 24.

under a pole it is not effective in generating any E. M. F. Furthermore, there are usually two or more circuits through the armature connected in parallel, and the voltage of the machine will, of course, be the voltage of each circuit. For bipolar machines there are two circuits connected in parallel, and for multipolar machines there are usually as many circuits in parallel as there are number of poles, although the windings may be varied and interconnected in multipolar machines so that the number of circuits in parallel may be different from the number of poles.

The voltage of any machine will therefore depend upon the number of conductors in series from brush to brush. For a bipolar machine, this will be one-half the total number of conductors on the surface of the armature. Of this one-half only those conductors opposite the pole piece are active. The voltage of such a dynamo will therefore be equal to the E. M. F. generated by a single conductor multiplied by one-half the total number of conductors, multiplied by that percentage opposite the

pole pieces. This percentage is usually from 70 to 80. This may be expressed by a formula as follows,

$$E = \frac{L \times v \times B \times \frac{N}{2} \times p}{10^8} = \frac{L \times v \times B \times N \times p}{2 \times 10^8}$$

in which L, v and B equal the quantities previously given, N the number of conductors on the surface of the armature and p equals the percentage of conductors opposite the pole pieces.

Example. A bipolar machine has 800 surface conductors, each 12 centimeters long, and the percentage opposite the pole pieces is 80. The speed is 1,200 revolutions per minute and the diameter of armature is 40 centimeters. The field density opposite the pole pieces is 3,000 lines per square centimeter. What is the voltage of the machine?

Solution. For this case $L = 12$, $v = 3.1416 \times 40 \times \frac{1200}{60} = 3.1416 \times 40 \times 20 = 2513.28$, $B = 3{,}000$, $N = 800$, and $p = .80$.

Hence,

$$E = \frac{12 \times 2513.28 \times 3000 \times 800 \times .80}{2 \times 10^8} = 289.529 \text{ approx.}$$

Ans. 289.529 volts.

Example. What field density is necessary for a bipolar machine, in order to give a voltage of 220 at 900 revolutions per minute? The armature has 400 surface conductors, is 30 centimeters in diameter and 16 centimeters long, the percentage opposite the pole pieces being 74.

Solution. Here $E = 220$, $L = 16$, $v = 3.1416 \times 30 \times \frac{900}{60} = 1413.72$, $N = 400$, $p = .74$, and B is to be found.

Hence,

$$220 = \frac{16 \times 1413.72 \times B \times 400 \times .74}{2 \times 10^8}$$

or $$16 \times 1413.72 \times 4 \times 74\, B = 2 \times 10^8 \times 220$$

$$B = \frac{2 \times 10^8 \times 220}{16 \times 1413.72 \times 4 \times 74}$$

$$= 6{,}571 \text{ approx.}$$

Ans. 6,571 lines per sq. cm.

The formula on page 25 may be altered slightly to give the voltage of any machine, depending upon its winding. For example, for a four-pole machine with four circuits in parallel

through the armature, the voltage will be that generated by one fourth of the surface conductors, and the formula becomes,

$$E = \frac{L \times v \times B \times N \times p}{4 \times 10^8}$$

It must be remembered that N equals the total number of surface conductors on the armature. For a ring-wound armature N would be equal to the number of turns, and for a drum-wound armature N would equal twice the number of turns.

Factors Determining Voltage. From the preceding it is clear that the voltage of a dynamo depends mainly upon three factors: speed, field strength, and length and number of conductors on the armature. The voltage may be increased by increasing any one of them. The speed of a machine is limited by mechanical considerations, and low speeds are greatly favored for this reason, and also to enable the driving engine and the generator to be directly coupled. The voltage obtained by using a large number of armature conductors is limited by troublesome sparking at the brushes, and the cost is also greatly increased. A high field strength is obtained by having large and powerful field magnets. A strong field greatly increases the weight of the machine and also increases the cost of the iron and field winding, but is advantageous on account of good regulation and reduction of sparking.

It must be remembered, however, that the formulas given above are for the theoretical values only, and these are somewhat reduced by armature reactions which will be considered on the following pages.

THE FIELD.

Magneto-Dynamo. The field of early forms of dynamos consisted of permanent magnets, and such machines were called *magneto-dynamos*. These were objectionable on account of their great weight (a very large magnet being necessary to give even a feeble field) and also on account of the gradual decrease in strength due to vibrations and inability to control the same. Very small machines of this type are still in use for light

work, such as ringing telephone bells, but larger machines have been replaced by those having electro-magnets.

Ampere-Turns. The necessary magnetization of the wrought iron, cast steel and cast iron, which is used for the field frames of dynamos is produced by passing a current through the windings upon the frame, and the strength of the field depends upon the number of turns in the coils and strength of current passing through them. In fact, the magnetizing force is proportional to the product of the number of turns in a coil and the strength of its current. This product of number of turns and the current in amperes is called the *ampere-turns*. As far as the amount of magnetization is concerned, it is immaterial how the number of turns and current strength are related to each other as long as the product is the same. That is, it makes no difference whether there are 25 turns with 2 amperes, or 10 turns with 5 amperes; the product is 50 ampere-turns.

Saturation of Magnets. There is a great difference between the relation of the ampere-turns or magnetizing force and the field strength produced thereby for different values in the magnetizing force. When the number of ampere-turns is small, the magnetization of the iron will increase rapidly for a small increase of magnetizing force, and as the ampere-turns become greater, the resulting field strength increases almost in direct proportion. The increase is not, however, in direct ratio. This rapid increase in field strength continues to a certain point and then the increase begins to be less and less for an equal increase in ampere-turns, until finally a great increase in ampere-turns produces practically no increase in field strength. The iron is then said to be *saturated*, or to be in a state of *magnetic saturation*. An increase in the magnetizing force when this point is reached is, of course, of no advantage, and results simply in a waste of energy.

Fig. 25 shows graphically the relation between the magnetizing force and the corresponding field strength for a sample of wrought iron. In this plot the abscissae or horizontal distances represent the magnetizing force H in ampere-turns, while the ordinates or vertical distances represent the field strength or induction B, in number of lines per square centimeter. The small circles on the curve represent the points obtained by experi-

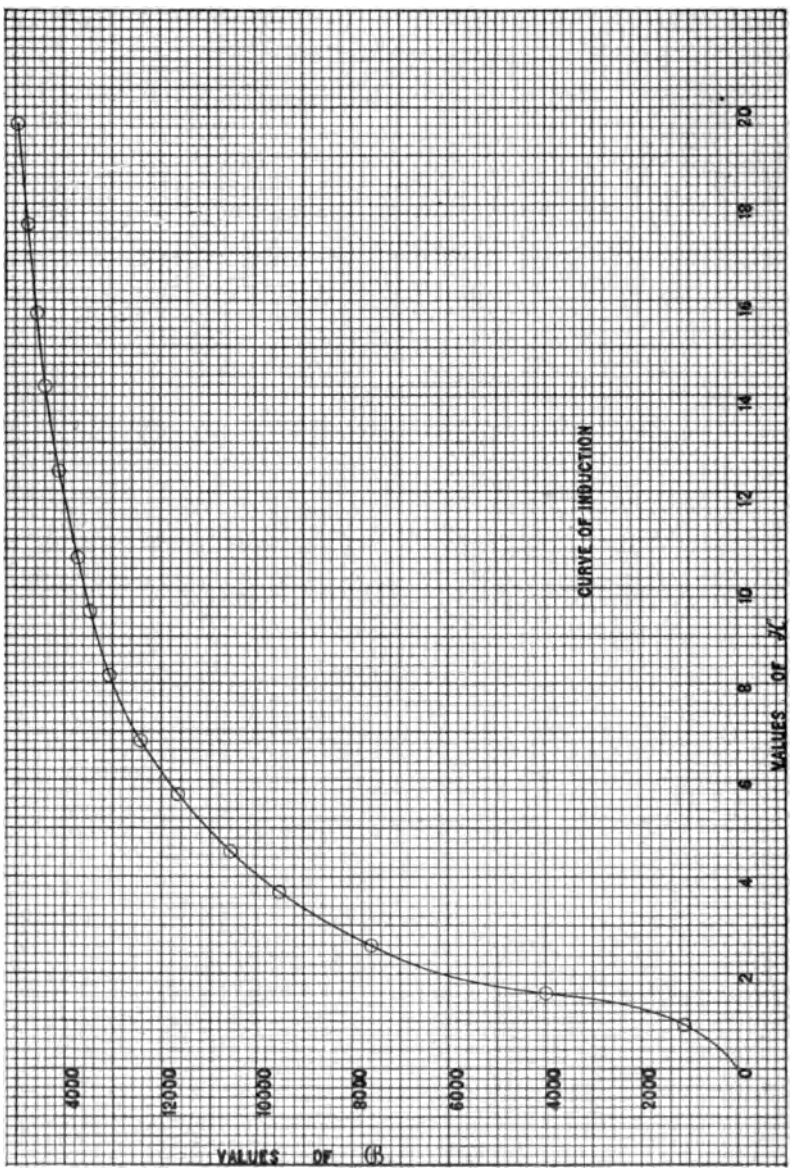

CURVE OF INDUCTION
VALUES OF ℋ
VALUES OF ℬ
0
2
4
6
8
10
12
14
16
18
20
2000
4000
6000
8000
10000
12000
14000

Fig. 25.

ment, and by means of which the curve is obtained. It appears from the curve that an increase in magnetizing force from 0 to .5 does not increase the magnetic induction nearly as much as does the increase from .5 to 1.0, showing that it requires some little force to move the molecules from their irregular position into the more symmetrical arrangement which they are supposed to assume when magnetized. The value of the field strength is about 1,300 lines per square centimeter for 1 ampere-turn, and is 9,900 for 4 ampere-turns, showing the increase to be very rapid. For 8 ampere-turns the field density is 13,000 lines, showing the proportional increase to be much less for the field density than for the magnetizing force, and beyond this point the increase in field

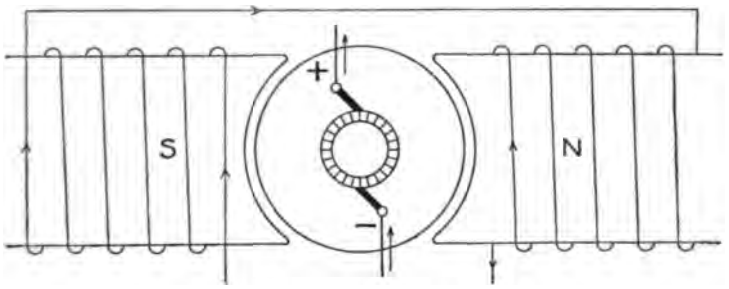


Fig. 26.

strength becomes gradually less and less, until the curve approaches a straight horizontal line, when the iron is saturated.

Types of Field Windings. There are four different types of field windings depending upon the method of excitation, giving rise to the following four classes of dynamos:

1. The *separately excited* dynamo.
2. The *series* dynamo.
3. The *shunt* dynamo.
4. The *compound* dynamo.

Each will now be briefly considered in the order named.

Separately Excited Dynamo. A separately excited dynamo is one having its field coils excited from some outside source, such as a battery or another dynamo. Fig. 26 represents such a machine, the two poles being excited by an outside current, and the current from the armature being available for supplying lamps,

motors, etc. In the separately excited machine the field excitation may be maintained nearly constant irrespective of the change in load put upon the dynamo, but it requires an outside current supply. There are but few direct current machines having separate field excitation, but on account of the nature of the current derived from alternating current machines they are usually separately excited. A small direct current dynamo called its *exciter* is used for this purpose.

The Series Dynamo. We now come to consider dynamos which are self-exciting; that is, they supply their own field current and are therefore self-contained. Of these, the simplest is the series dynamo or *series-wound* machine, and in this type the main

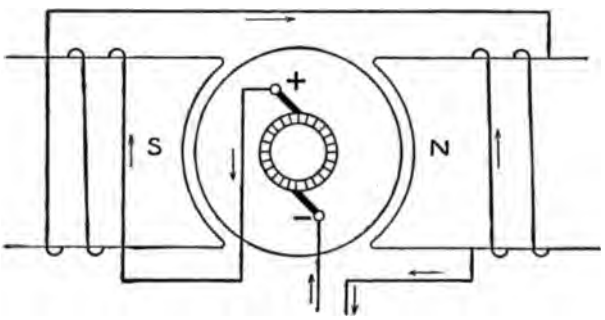


Fig. 27.

current from the armature is passed through the field coils and then to the external circuit. Such a connection is represented in Fig. 27. As these coils carry the main current of the machine they are of comparatively large size, but owing to the large current, only a small number of turns are required to give the necessary magnetization.

The series dynamo has the disadvantage that it cannot be made to start action until a certain speed has been obtained, unless the resistance of the external circuit is below a certain limit. Furthermore, the dynamo requires a special regulator to control the current and voltage with change of load, and about the only practical use for which it is adapted is for operating arc lights.

Shunt Dynamo. In the shunt dynamo or *shunt-wound* machine, the current from the armature has two paths through

which to flow. One is through the external circuit and the other is through the field coils. The connections are represented in Fig. 28. The current from the armature divides at the positive brush and passes through the external circuit to the negative brush, and also through the shunt windings to the negative brush,

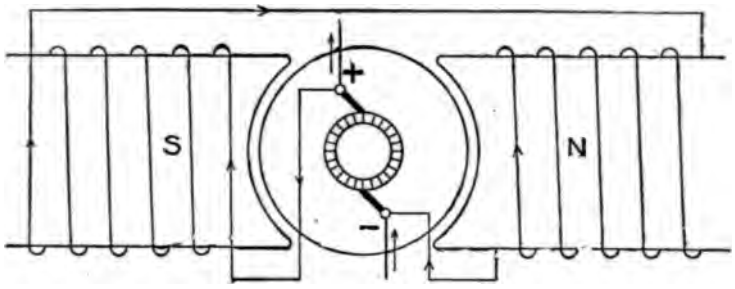


Fig. 28.

the field coils acting as a shunt to the external circuit. In this machine the field windings consist of many turns of fine wire, and take only a small part of the current from the armature; they

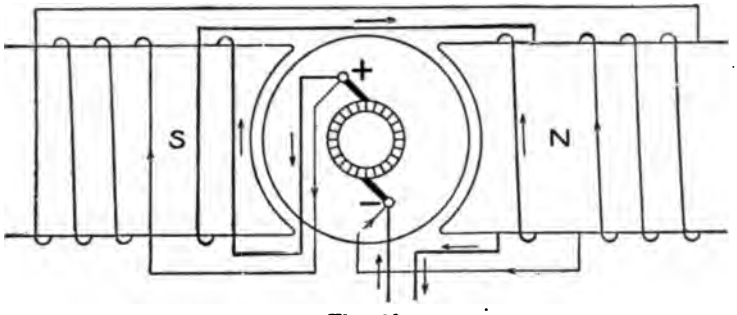


Fig. 29.

differ greatly from the series machine where there are but few turns carrying a large current.

The shunt-wound machine is much better adapted for practical service, such as lighting, and for supplying current to motors, than the series machine, but has been largely replaced by the machine next to be considered.

Compound Dynamo. The compound dynamo or *compound-wound* machine is a combination of the series and shunt windings.

The connections are shown in Fig. 29. In addition to the shunt winding connected from brush to brush, the main current is also passed through a few turns of large wire in series with the external circuit. With this arrangement the disadvantages of the shunt machine are overcome, and a machine which requires almost no attention during changes in load is produced; that is, the machine is practically self-regulating, and is used almost entirely for supplying current for incandescent lighting and power.

The action of the above considered machines is more fully considered in a following section.

Self-Excitation. As the energy required to excite the field magnets is a very small part of that which the machine is capable of supplying, it is evident that after a machine is once running there is no difficulty in maintaining the field strength. The question naturally arises as to the production of current at starting. This is explained by the fact that iron, after it is once magnetized, retains a certain amount of magnetism after the magnetizing force is withdrawn; this is called *residual* magnetism. Hence as the armature is rotated within this weak field, a slight E. M. F. will be generated which is sufficient to supply a feeble current to the field windings. This increases the field strength slightly, which in turn still further increases the E. M. F., and so on until the maximum voltage is attained. This action is called *building up*.

ARMATURE REACTIONS.

On the preceding pages we have considered the fundamental principles upon which the generator is based, and also its general construction. We shall now look into some of the important actions taking place during the operation.

We shall first consider the simple action of the armature unmodified by reactions, and then see how this condition is altered.

Simple Action. Fig. 30 represents an eight-coil ring armature of a bipolar machine. Coils C and G are moving directly across the strongest part of the magnetic field, and are therefore generating the maximum E. M. F. Coils B and F are just entering the field, and D and H are leaving the field and generating less E. M. F. than C and G.

Coils A and E are not cutting across the field, and therefore generating no E. M. F. Now all coils on the right-hand half of the ring are generating an E. M. F. in the same direction, and therefore assist each other to give the total E. M. F. of the machine, while all coils on the left-hand half are also assisting each other, but generating an E. M. F. in the opposite direction to that of the right-hand half. The current induced in the outside wires at the right-hand side approaches the observer, while the current in the outside wires at the left recedes from the observer, causing an ascending current in each half of the ring from the lower brush to the upper brush. It will be noted that each brush for the position shown, bears upon two commutator bars, and the upper brush takes the current directly from coils B and H, while the lower brush conducts the current directly to coils D and F. The thickness of brushes is always sufficient to bridge the insulation between commutator bars

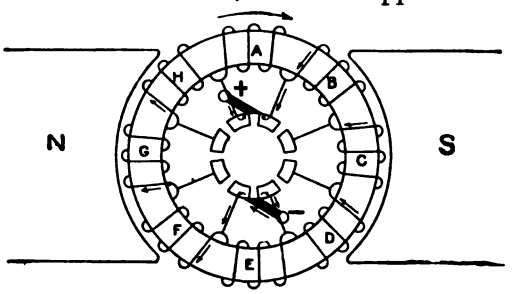


Fig. 30.

Coils A and E are therefore momentarily short circuited or cut out of the armature circuit, and as each coil takes these positions, each is successively short circuited. The current which the coil formerly carried then seeks the direct path through the commutator bar to the brush. After being short circuited and carrying no current, the coil is then grouped with the other half of the ring, and a current is set up in the opposite direction through the coil. Hence as each coil passes from one half of the ring to the other, the current through it in one direction is interrupted, which renders the coil temporarily inactive, and as it passes to the other side of the ring, a current is set up in the opposite direction. In this manner the commutation of currents takes place.

A plane through the inactive position of the coils is called the *neutral* plane, and coils A and E are said to be in the neutral positions.

Magnetic Field Due to Field Winding. The magnetic field, created by the field coils alone, and unaltered by armature reactions, is represented by Fig. 31. The small circles represent the cross section of each wire, of which only a few are shown, and the direction of current in the field coils is indicated by the dots

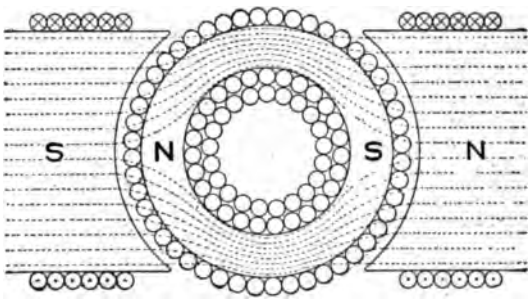


Fig. 31.

and crosses within the circles. In those wires having crosses, the current is flowing from the observer, the cross indicating the tail of a retreating arrow, and in those wires having dots the current is flowing towards the observer, the dot indicating the point of an advancing arrow. The field, created by a current in the field coils only, is uniform and passes through the armature core as shown.

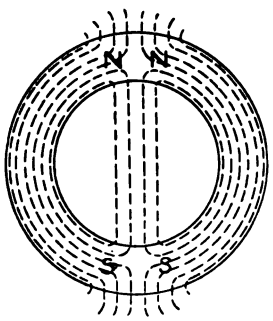
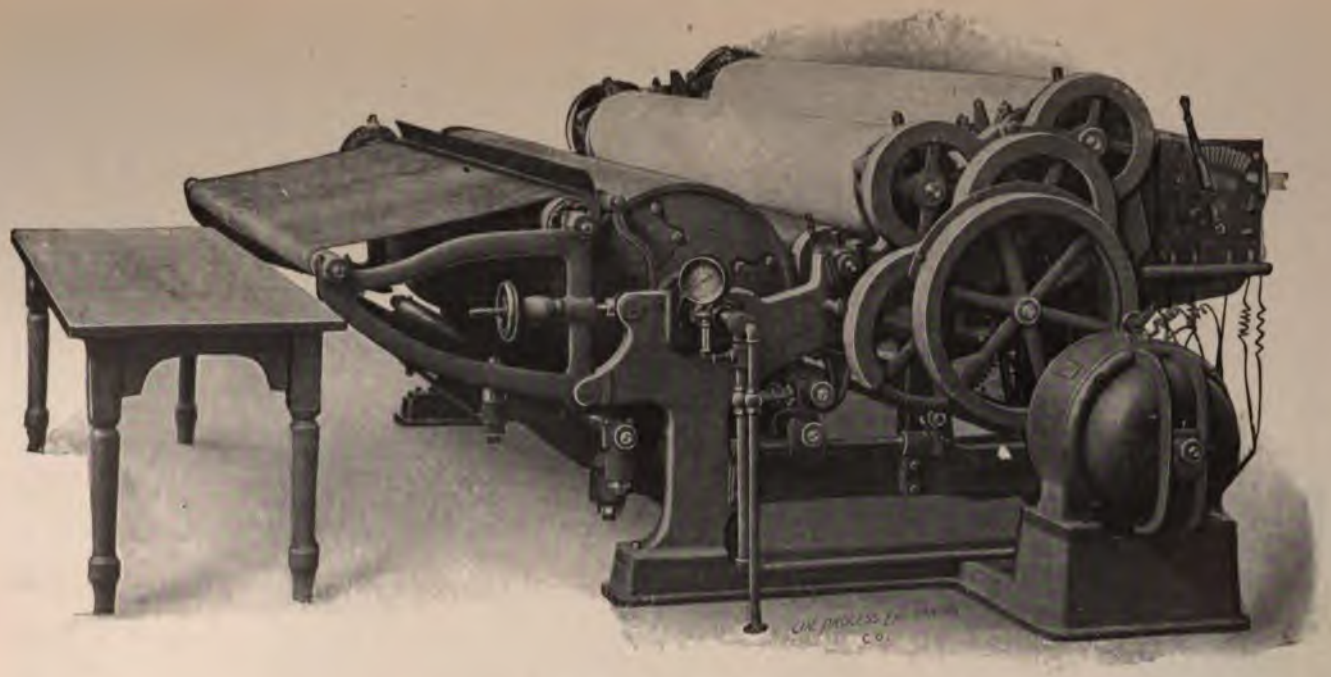


Fig. 32.

Magnetic Field Due to Armature Winding. When a generator is supplying current, the armature is magnetized by its own current, and the magnetic field in the armature due to its current alone is represented by Fig. 32. The current in each half of the ring magnetizes its half independently of the other, and for the arrangement shown in Fig. 30 each produces a north pole at the lower portion of the ring and a south pole at the top. The two like poles thus created adjacent to each other have a repellant effect and create what is termed a *consequent* pole, causing the magnetic lines to leave the ring at these points, part of the lines passing directly across the ring and part



FULLY ENCLOSED MOTOR

Driving Hercules Laundry Mangle.
Triumph Electric Company.

THE NEW
PUBLIC LIBRA
ASTOR,
TILDEN

passing outside the ring in curved lines from the lower portion to the top.

When a ring thus magnetized is between the field poles, the poles will serve as a path for many of the lines, and a field such as represented by Fig. 33 results.

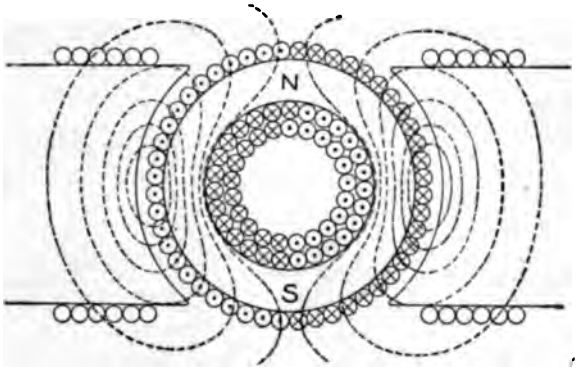


Fig. 33.

Resultant Field. When a machine is in operation, the magnetism due to both the field and armature windings is present, and the field obtained will therefore be the resultant of the two fields represented by Figs. 31 and 33. These fields, when united,

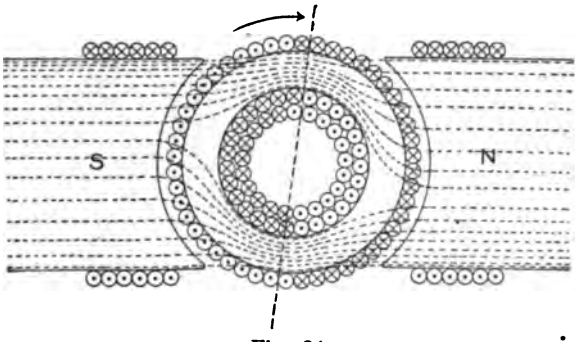


Fig. 34.

will give a resultant field, as represented by Fig. 34. The field due to the field windings being the stronger, will still maintain the same general course, but the effect of the armature is to produce a resultant field in an oblique direction. It also causes a

crowding of the magnetic lines at the tips of the poles where the conductors pass from under the same, and a weakening of the lines at the tips which the conductors are approaching. It thus appears that the neutral plane is turned somewhat in the direction of rotation as indicated by the dotted line. After passing from under pole pieces, the conductors generate but little E. M. F., and when they are in the neutral plane they generate none whatever; therefore from the above it appears that the brushes should be set in such a position that coils will be short circuited when in the neutral plane. Hence the brushes, instead of being placed midway between the poles in a ring-round machine will be

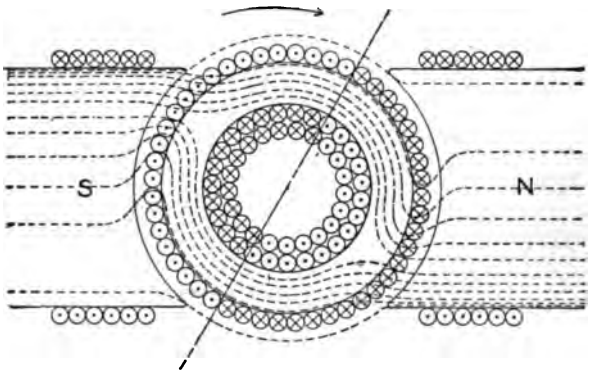


Fig. 35.

shifted slightly in the direction of rotation of the armature. The amount which the brushes are shifted from their mid-position is called the *lead* or *angle of lead.*

This shifting of the brushes causes a still further distortion of the resultant field, as the field due to the armature winding alone, instead of being vertical as represented in Figs. 32 and 33, will be inclined, and coincide with the neutral plane. This inclination aggravates the distortion, causing the neutral plane to be shifted to a greater degree than represented by Fig. 34. The actual result obtained will therefore be better represented by Fig 35, all conductors on one side of the neutral plane carrying currents in an opposite direction to those on the other side.

There is another cause for additional shifting of the brushes which causes a slightly greater distortion. This is due to self-induc-

tion of the armature coils. From the preceding pages it appears that each coil is short-circuited as it passes by the brushes; the current which the coil carried as it approached a brush ceases to flow, and as it passes to the other side, a current in the opposite direction is set up. On account of self-induction, however, the current which the coil formerly carried tends to continue, and the current in the opposite direction is choked back for a slight interval of time, as self-induction tends to oppose a decrease or increase of current strength. In order to counteract this effect, the brushes are shifted a slight amount in the direction of rotation, so that when each coil is short-circuited it is at that time already somewhat effective in cutting lines of force, so that a slight E. M. F. is generated which hastens the time of decrease in current in one direction, and assists the increase of current in the opposite direction.

We may sum up the effect of armature reaction as follows:

1. The magnetic field due to the armature windings is at right angles to that of the field windings, giving a resultant distorted field.

2. On account of this distortion, and in order to prevent sparking, the brushes must be shifted in the direction of rotation of the armature, and this new position of the brushes in itself produces a still greater distortion.

3. The further shifting of the brushes to overcome the effects of self-induction causes additional distortion.

Shifting of Brushes with Variable Load. When the armature supplies no current and therefore has no load, the field is substantially uniform, as no distortion due to the armature exists. The brushes may therefore be set at the mid-position between the poles. When the load is light, the small armature current causes but little distortion, and therefore the brushes need only a slight lead to secure sparkless running. As the load increases and the armature current becomes greater, the distortion is correspondingly increased, and consequently the proper position for the brushes changes with the load. Hence in the operation of generators, a variation in load will cause sparking at the brushes unless they are shifted to the proper positions. Many machines are now so well designed that but little shifting is necessary from no load to

full load, and in some machines the necessity is entirely overcome by special compensating arrangements. Of course, if the field due to the field windings is made very powerful compared with that due to the armature, the distortion will be proportionately less, and in many machines now made, where this plan is carried out, there is little or no need of shifting the brushes with change in load.

Distortion Due to Drum-Wound Armatures. In the above discussion of armature reactions we have referred to distortion due to ring-wound machines only. The same effect in a lesser degree takes place with drum-wound armatures.

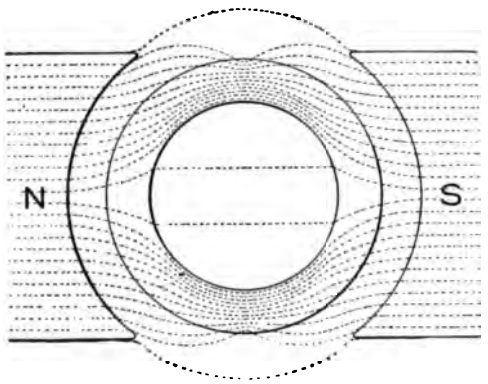


Fig. 36.

Magnetic Leakage. If the magnetic circuit is well designed and made of ample cross-section, practically all the lines of force will pass through the armature core from pole to pole. All lines which do not pass through the core are of course useless, and the E. M. F. generated is less in a corresponding degree. Fig. 36 illustrates the manner in which lines may pass from pole to pole without being of any service. This is called magnetic leakage.

LOSSES IN THE GENERATOR.

There is always some loss in converting the mechanical energy necessary to drive a generator into electrical energy. That is, if 15 horse-power is necessary to drive a certain machine, the equivalent electrical energy derived from the same is always somewhat less. For example, the electrical equivalent of 15 horse-power is $15 \times 746 = 11{,}190$ watts, but instead of having this amount available at the dynamo terminals, there may be perhaps 90 per cent of this value, or 10,071 watts.

We shall now consider separately the various losses, all of which are dissipated in the form of heat.

These may be classified in two groups, known as the *electrical* losses and the *stray power* losses, and are as follows:

Electrical losses.

(*a*) Armature conductor $I^2 R$ loss.

(*b*) Field wire $I^2 R$ loss.

Stray power losses.

(*c*) Friction of bearings.

(*d*) Friction of brushes.

(*e*) Friction due to air resistance.

(*f*) Waste currents in coils during commutation.

(*g*) Hysteresis in armature core.

(*h*) Eddy or Foucault currents in armature core.

(*i*) Eddy or Foucault currents in pole pieces.

(*j*) Eddy or Foucault currents in armature conductors.

Of these the electrical losses vary with the load put upon the machine, whereas the stray power losses remain practically constant for all loads. As the stray power losses are always present to the same degree whatever the load may be, it is desirable that they should be as low as possible, since on light loads they may be a considerable proportion of the total power.

Electrical Losses. The electrical losses are those due merely to the resistance of conductors through which a current flows, and may be computed by taking the square of the current passing multiplied by the resistance, or $I^2 R$; where I is the current and R the resistance of the circuit. All circuits carrying a current, whether windings of a generator or mains which distribute power, are subject to this loss of energy. Hence if the resistance and current are known, the power lost may be readily obtained.

For example, if the resistance of a circuit is 80 ohms and the current 40 amperes, the power lost will be $40^2 \times 80 = 128{,}000$ watts, or 128 K. W. The power lost may also be computed if the current and E. M. F. applied to the circuit are known, by taking the product of the two quantities. This is evident, as from Ohm's law $I = \frac{E}{R}$, and substituting this quantity for one I in $I^2 R$, we have $I \times \frac{E}{R} \times R = IE$, where E is the E. M. F., applied to the circuit. In the above problem the E. M. F. applied to the circuit is, by Ohm's law, $E = RI = 80 \times 40 = 3{,}200$ volts, and

the loss in watts is, therefore, $40 \times 3{,}200 = 128{,}000$ watts = 128 K. W., the same as above.

The data for computing the loss in the field windings of a machine can be easily obtained. It is merely necessary to measure the resistance of the windings and the current in the same, or to measure the current and the voltage applied to the terminals of the field windings. The resistance of shunt windings will always be high and the current small, while the resistance of series windings will always be low and the current large.

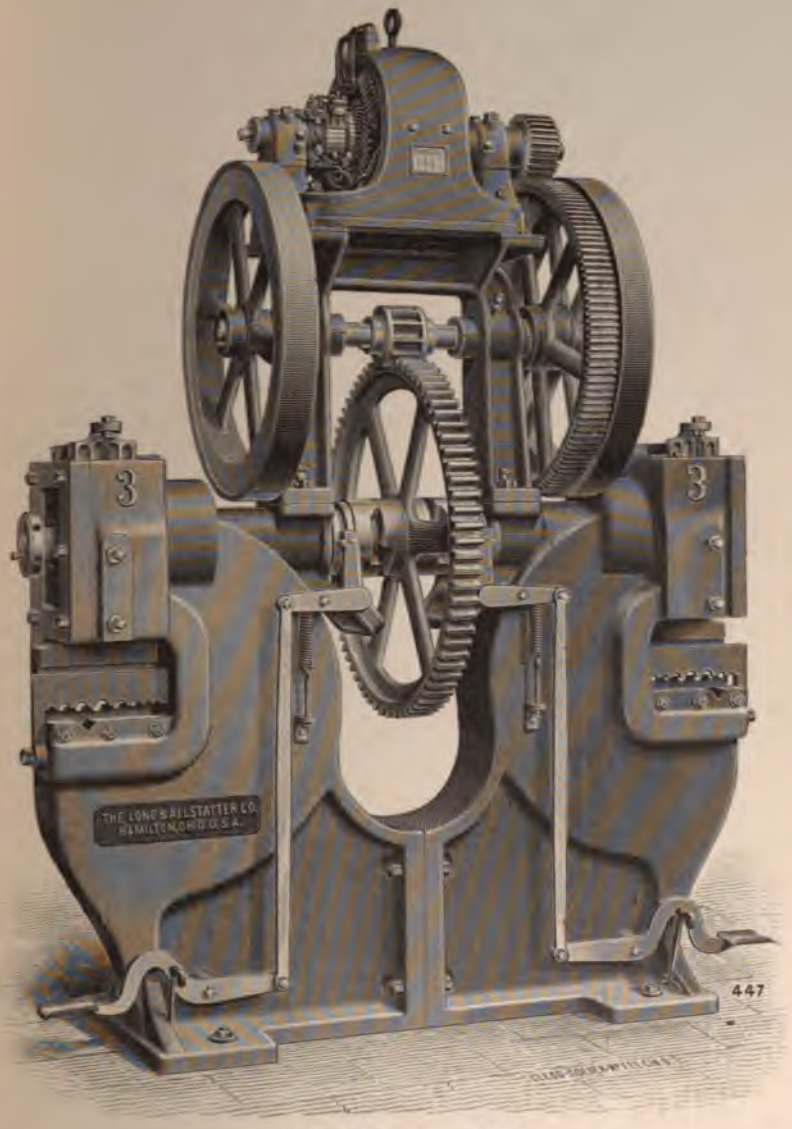
The data for calculating the loss in the armature is obtained with more difficulty. As the armature is itself generating an E. M. F., the fall of potential in the armature due to its resistance or the *drop* in the armature cannot be measured, and we are therefore compelled to compute the loss from resistance measurements and must use the formula $I^2 R$. The current can be easily measured, but there is some difficulty in measuring the resistance accurately. In this resistance, the armature winding, commutator, brushes and resistance of contacts between commutator and brushes are included. The total resistance is very small, and therefore a slight error in its measurement will make a considerable percentage difference. Also the resistance must be measured when the armature is not rotating, and the measurement obtained may be somewhat different from the resistance when the machine is in operation.

As the resistance of the conductors is greater when hot than when cold, the resistance measurements for calculating the loss in the armature as well as in the fields must be made after the machine has been in operation at full load for a few hours, when all parts will be thoroughly warmed up.

Example.— The resistance when hot of the shunt winding of a certain 120-volt 200-ampere shunt machine is 98 ohms. The resistance of the armature when hot is .019 ohm. What are the electrical losses at full load?

Solution.— The voltage of the machine which is applied to the shunt terminals is 120 volts, and by Ohm's law the current in the shunt windings is

$$I = \frac{E}{R} = \frac{120}{98} = 1.22 \text{ amperes.}$$



DOUBLE BAR-IRON SHEAR.

Motor Driven.

The Long and Allstatter Co.

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AND
TILDEN FOUNDATIONS

The loss in the field winding is therefore $I^2 R = 1.22^2 \times 98 = 146$ watts approximately.

Both the main current and the shunt current pass through the armature; hence the armature current is 201.22 amperes, and the resistance is .019 ohm; the loss is therefore $(201.22)^2 \times .019 = 769+$ watts.

The electrical losses are consequently $146 + 769+ = 915$ watts.

Ans. 915 watts.

Example.— A 500-volt compound-wound generator is designed to supply 650 amperes. The armature resistance is .009 ohm. The current in the shunt winding is 3 amperes, and the resistance of the series winding is .0011 ohm. Find the total electrical loss of the machine.

Solution.— As the current in the shunt field winding is 3 amperes, and the voltage applied to the terminals is 500, the loss in watts is given directly by their product, or $3 \times 500 = 1{,}500$ watts.

As the main current of the machine passes through the series winding, the resistance of which is .0011 ohm, the loss therein is $650^2 \times .0011 = 464.75$ watts. Likewise the loss in the armature is $653^2 \times .009 = 3{,}837.6$ watts.

The total loss due to resistance therefore equals $1{,}500 + 464.75 + 3{,}837.6 = 5{,}802$ watts.

Ans. 5,802 watts.

Example.— A 220-volt compound dynamo delivers 300 amperes. The armature resistance is .014 ohm, the shunt winding takes 2.18 amperes, and the fall of potential in the series coil is .54 volt. What are the electrical losses?

Solution.— The loss in the shunt field is $220 \times 2.18 = 479.6$ watts. The current passing through the armature is $300 + 2.18 = 302.18$ amperes, and the armature loss is therefore

$$(302.18)^2 \times .014 = 1{,}278.4+ \text{ watts.}$$

The loss in the series coil is the product of the lost voltage (i.e., the drop) in it and the current; that is, $.54 \times 300 = 162$ watts. Hence the total electrical losses are $479.6 + 1{,}278.4 + 162 = 1{,}920$ watts.

Ans. 1,920 watts.

Friction Losses. The friction losses include those due to mechanical friction of the bearings and of the brushes upon the commutator and also the friction caused by the resistance of the air acting on the rotating armature.

The friction of the bearings varies with the type of machine, whether belt driven or direct connected to the engine, type of bearing, lubrication, etc.

The loss due to bearing friction was formerly considerable, but the bearings of modern dynamo-electric machines have been designed and constructed with great care with the result that friction from this source has been reduced to a minimum. The bearings are usually made self-oiling by means of metal rings which rest upon the shaft and dip into oil which is contained in a reservoir in the bearing. As the shaft revolves, the rings carry the oil up to the shaft. In this manner almost perfect lubrication is secured. In some cases ball bearings have been used with good results; they reduce friction and lessen the cost of lubrication. Ball bearings are not extensively used on account of some mechanical difficulties which have not yet been entirely overcome.

The brush friction is subject to great variation. It is important that the brushes bear upon the commutator with sufficient pressure to insure good electrical contact. Brush holders are usually arranged so that the pressure of the brushes may be varied to obtain the best results. Although brush friction may sometimes be considerable, it usually amounts to a very small percentage of the total loss.

The resistance of the air upon the armature is usually insignificant except when the armature is arranged to act as a fan for the purpose of ventilation, and even then the loss from this source is so slight that it need hardly be considered.

Hysteresis Loss. As an armature rotates, the magnetization of its core is constantly changing at every point. The magnetic lines in passing through the armature from pole to pole cause varying degrees of magnetization in its different parts, and the rotation of the armature brings every part of it successively through these changes. Hence that part of the armature in the neutral plane is magnetized to the highest degree with lines passing through it in one direction; when opposite a pole, the

magnetization is a minimum, and when in the next neutral plane it is again magnetized to the highest degree but with lines passing in the opposite direction. All parts of the armature core are therefore being constantly magnetized in one direction, then demagnetized and magnetized in the opposite direction, again demagnetized, and so on as each pole is passed. This gives rise to what is called hysteresis loss, which will now be considered.

When a piece of iron is subjected to an increasing and decreasing magnetizing force, the magnetization for equal magnetizing forces will not be the same, and it is found that the magnetism lags behind the magnetizing force, or in other words, the metal has a tendency to maintain any magnetic state which it has once acquired. This property of iron is called *hysteresis*, from a Greek word meaning "to lag behind."

Fig. 37 shows the hysteresis curve of a piece of wrought iron, or the resultant magnetization when the magnetizing force is varied. The abscissæ represent the magnetizing force in ampere-turns per centimeter of length, and the ordinates indicate the resultant magnetization in lines per square centimeter. Abscissæ to the right of the zero point represent positive values and those to the left negative, while ordinates above the zero point are positive and those below are negative. The curve which begins at A shows that the iron had some residual magnetism before any magnetizing force was applied. As the magnetizing force is increased positively, the magnetic induction gradually increases as in Fig. 37, until point B of the curve is reached. Then the magnetizing force is gradually withdrawn, but the magnetic induction does not fall as fast as it previously rose, for when the magnetizing force is reduced to 10, the induction is nearly 14,000 lines instead of 12,800, as it was on the ascending curve. When the magnetizing force is reduced to zero, the induction is still high, as represented by point C of the curve. Increasing the magnetizing force still further in a negative direction gives an induction curve to point E.

A gradual decrease of the magnetizing force to zero and an increase in a positive direction to a maximum gives the curve through points $E\ F\ G\ H$. It may be noted that point H does not coincide with point B, although the magnetizing force is increased

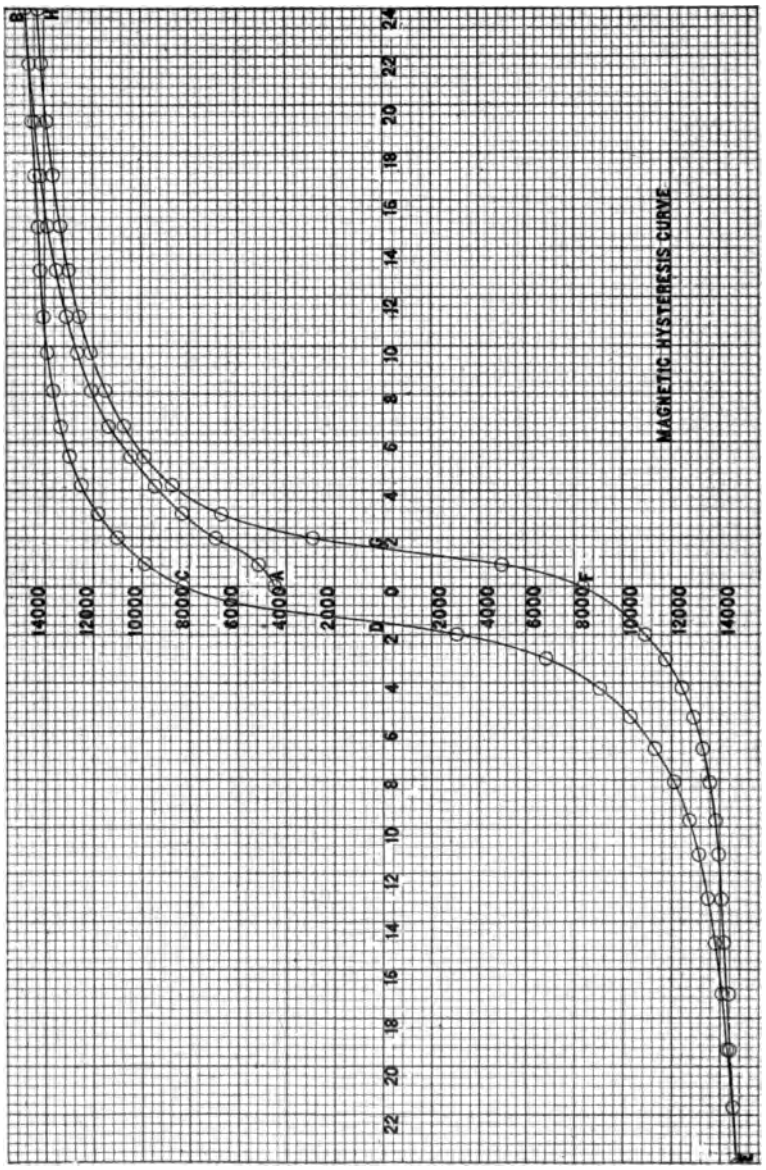
MAGNETIC HYSTERESIS CURVE
14000
12000
10000
8000 C.
6000
4000 A
2000
0
2000
4000
6000
8000 F
10000
12000
14000
2
4
6
8
10
12
14
16
18
20
22
24

Fig. 87.

from zero to a maximum for both curves. However, in the first magnetization from *A* to *B* the induction had a considerable positive value at the beginning, whereas in the curve *F G H* it had a large negative value which had to be overcome. If the magnetizing force were now decreased, reversed, increased, etc., a second curve similar to *B C D E F G H* would be obtained. Such cycles of magnetism as described above always give curves with an enclosed area.

This series of changes is what takes place in the core of an armature, and it is evident that the resultant magnetism always lags behind the magnetizing force as if there were a certain molecular friction of the iron which had to be overcome.

There is, therefore, a certain loss of energy due to hysteresis which is dissipated in the form of heat. The amount of this energy is proportional to the area enclosed by the curve, and it is therefore an easy matter to judge of the comparative magnetic qualities of two samples of iron by plotting the hysteresis curve of each.

The harder the iron, the greater the hysteresis loss. This loss varies as the 1.6 power of the magnetic induction and is also proportional to the rate at which the reversals of magnetism take place, and of course, the greater the amount of metal in which the reversals occur, the greater the total hysteresis loss.

The heating which occurs in the core of an armature due to hysteresis should not be confused with the additional heating due to eddy or Foucault currents. Hysteresis causes heating even if the core is carefully laminated.

Fig. 38 shows two hysteresis curves drawn one over the other, one of which is from a sample of wrought iron and the other from a sample of steel.

The curve enclosing the smaller area is for wrought iron, and the larger for steel. Since the area enclosed by the hysteresis curve is the measure of energy dissipated in heat due to hysteresis, it is evident that the hysteresis loss for wrought iron is much less than for steel. Wrought iron would, therefore, be better adapted for use in armature cores.

The loss due to hysteresis cannot be accurately determined. For very soft iron where the hysteresis curve encloses a small

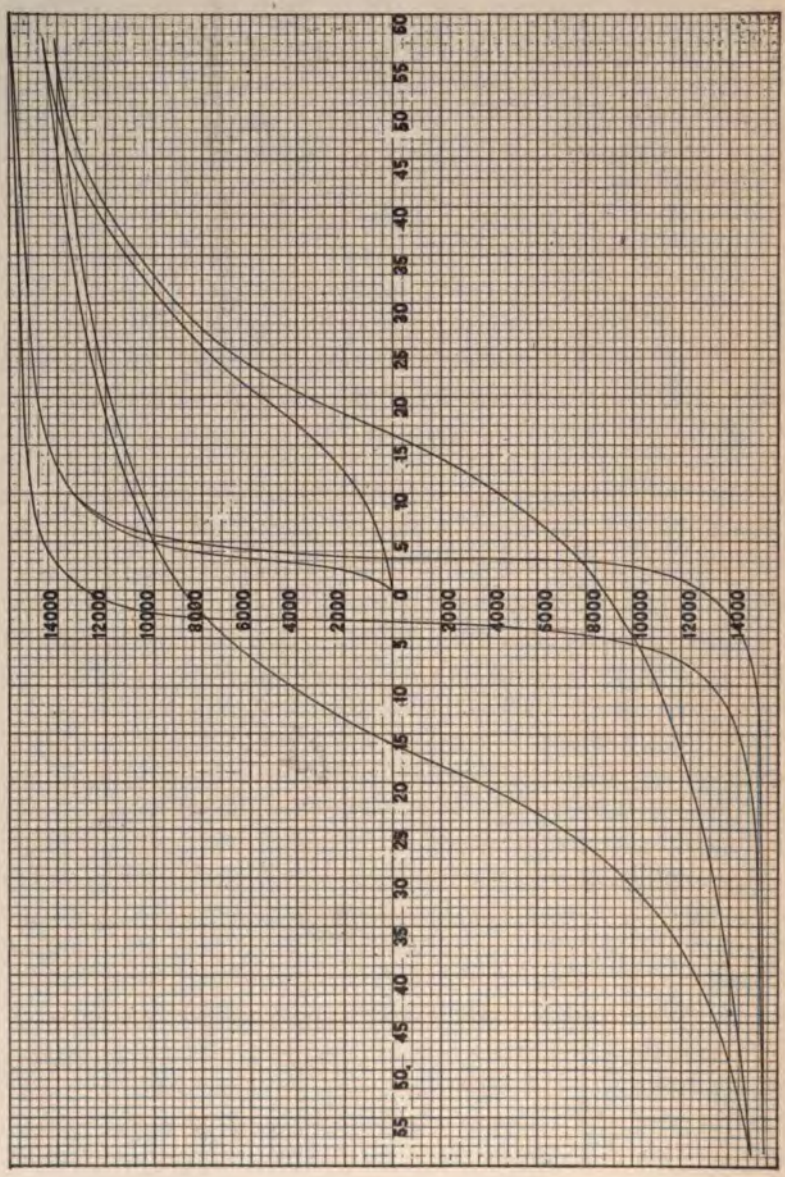
14000
12000
10000
8000
6000
4000
2000
0
2000
4000
6000
8000
10000
12000
14000
5
10
15
20
25
30
35
40
45
50
55
60

Fig. 38.

area the loss of energy during a complete reversal of magnetism is slight; with hard iron the amount of energy wasted per cycle is somewhat greater, but in practice the loss from this source is usually small. In order that this loss may be as small as possible the softest wrought iron or steel should be selected for armature cores.

Eddy Current Loss. We know that whenever conductors are moved in a magnetic field in such a manner as to cut across the lines, or when the field about the same is varied, an E. M. F. is induced which will cause a current to flow if a closed circuit exists. This principle applies to large metallic masses as well as to the conductors, and therefore currents may be set up in a generator where they are useless, thus causing undesirable heating of parts and loss of energy. Such currents are called eddy or Foucault currents.

The armature core, if made of one solid mass, is subject to these wasteful currents to an excessive degree, since it consists of a conducting mass revolving in a magnetic field. It is evident that the outer surface of the armature core cuts across the magnetic field the same as the conductors upon it, and an E. M. F. is therefore induced in the iron itself, tending to set up currents near its surface. The direction of these currents will be at right angles to the lines of force or the induced current in the exterior of the armature core will be parallel to the current in the armature conductors. The interior portion of the core serves to complete the circuit for these currents, and therefore innumerable currents, due to this cause, will exist in the core itself. The E. M. F. induced may be slight, but the resistance of the core is so small that the resultant currents may be large. These currents are always strongest near the exterior surface of the armature core. This eddy current loss described above varies as the square of the speed and also as the square of the magnetic induction.

Lamination. The value of such currents can be decreased by reducing their E. M. F. or by increasing the resistance which is offered to their flow. These results can be accomplished by constructing the armature core of thin sheets of iron carefully insulated from each other. These thin sheets or discs are placed perpendicular to the axis of the armature, thus being perpendicular

to the direction of induced currents, but parallel with the lines of force passing through the core. Consequently they do not interfere with the passage of magnetism from pole to pole, nor increase the magnetic resistance of the armature. They do, however, effectually interrupt and reduce the eddy currents because such currents can then exist only within each separate disc, as shown in Fig. 39, and if the discs are made sufficiently thin and the insulation between them is good, the loss due to wasteful currents is slight. An armature built up of discs or thin sheets of iron is said to be laminated. The thickness of the discs should not exceed two millimeters, and they should be insulated by varnished paper, enamel, or by being slightly oxidized on the surface.

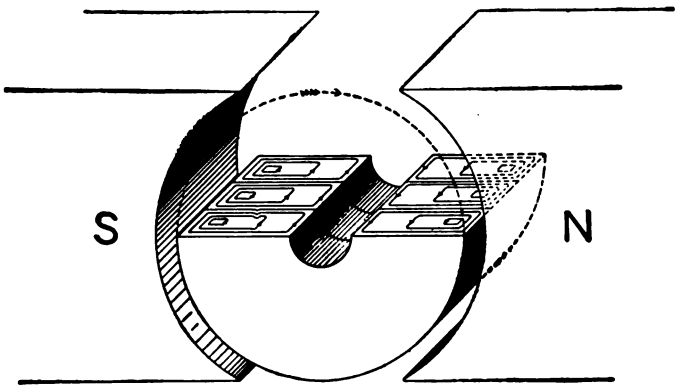

Fig. 39.

Eddy Currents in Pole Pieces and Armature Conductors. Polar tips in which magnetization varies become heated. Hence tips are now laminated, the laminations being parallel to the lines of force but perpendicular to the direction in which currents would be induced. Armature conductors are also subdivided for the same reason, and the loss in eddy currents is reduced to a total of usually less than one-half of 1%.

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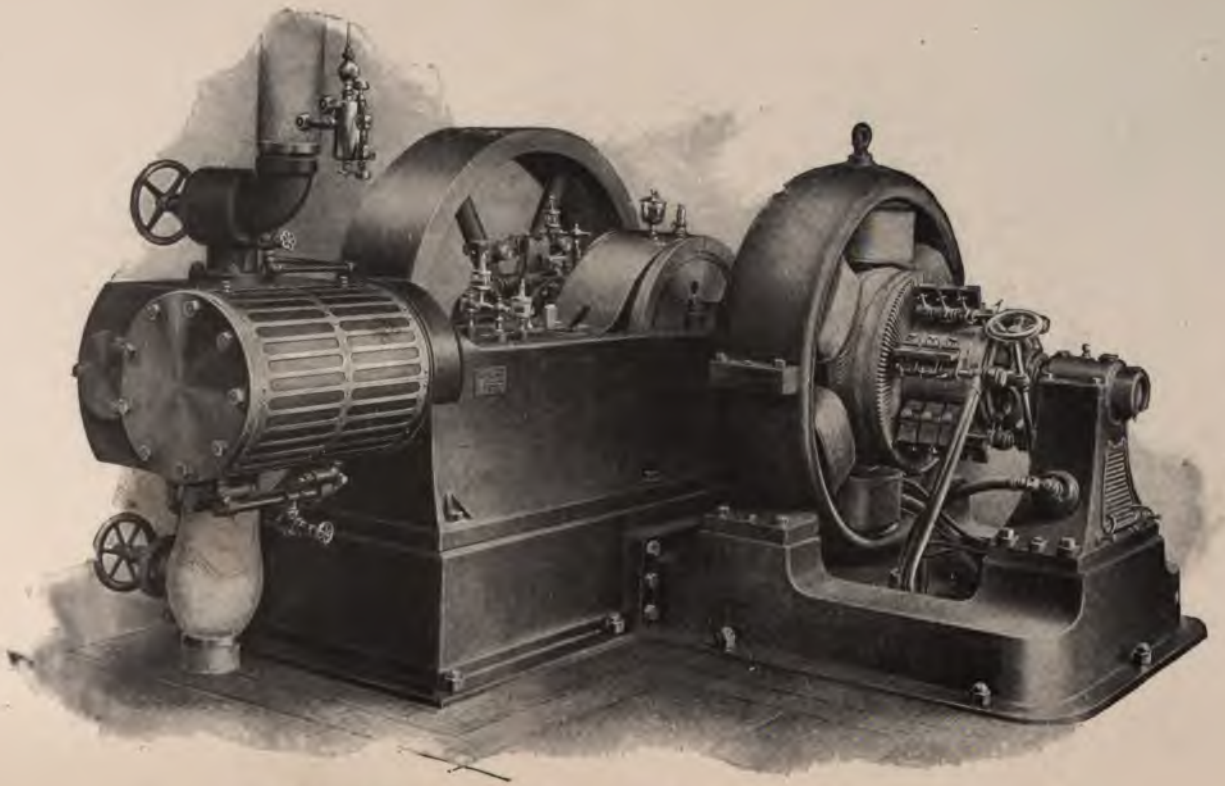


HORIZONTAL ENGINE DIRECT-CONNECTED TO GENERATOR.

New York Safety Steam Power Company.

DIRECT CURRENT DYNAMOS.

Having become familiar with some of the fundamental principles and laws governing the operation of a dynamo by a study of electro-magnetic induction, one is prepared for a more detailed study of the machine. The three important types of dynamos, the series, the shunt and the compound, have already been briefly explained, but will now be considered more in detail, and their properties will be more fully explained and illustrated by diagrams.

All of the important parts of the dynamo, such as the armature, the commutator, the brushes and brush-holders, and the field will now be treated separately and in detail.

In general, dynamos are used to furnish either light, heat or power. A dynamo receives at the pulley a certain amount of mechanical energy, which it transforms into electrical energy and delivers through the circuits with which it is connected. The power in a circuit is equal to the product of the difference of potential, E, between the terminals of the dynamo and the current, I, flowing in the circuit, or $E\,I$. When this product, $E\,I$, is great, a large amount of work is expended in the circuit, and to express this fact it is said that a heavy load has been put upon the dynamo. The value of $E\,I$ is increased by increasing either E or I, or both; that is, the load on the dynamo is increased when a larger current comes from it, or when the same current flows, but at a higher voltage.

We have seen that electrical power is measured in units, to which the name watt is given, a watt being the power of 1 ampere under a pressure of 1 volt; the product of the number of amperes and the voltage of a circuit is therefore its power. A dynamo which maintains a difference of potential between its terminals of 10 volts, and which delivers through the circuit connected with its terminals 5 amperes of current, is furnishing

energy at the rate of 50 watts. Had this same dynamo been working at a difference of potential or pressure of 25 volts, and had it been delivering only 2 amperes in the circuit, it would have still been working at the rate of 50 watts. It makes no difference in the amount of power what the pressure or the current is, as long as they are of such magnitudes that their product remains the same; the dynamo will then furnish the same amount of energy per unit of time, and consequently it will take the same pull on the belt, and the same effort in the engine to drive it.

These considerations suggest two methods for distributing power and light. The necessary condition of supply is that the dynamo must be ready to meet a demand which varies between certain limits. This may be done by causing the dynamo to keep the voltage at its terminals constant at all times, and to vary the current according to the demand; or the dynamo may keep the current supplied constant, and vary the voltage at its terminals according to the demand for energy. It will make no difference to the driving power which is done. It has, however, for many reasons, been found most convenient to supply incandescent lighting systems by the first method, and arc lighting systems by the second. Power distribution has occasionally been accomplished by the second method, but the first is generally used.

In the study of **Direct Current Dynamos** it will therefore be of advantage to divide the subject into two parts: (1) Constant Potential Dynamos, machines that supply current at a constant pressure for all loads; and (2) Constant Current Dynamos, machines that supply a current of constant strength for all loads.

By having more lamps or running more motors on the circuit we increase EI, or the load upon the dynamo. In constant potential machines, E remains constant for any change in the number of lamps or motors on the circuit, within the limits of the capacity of the machine; hence, to increase the load on the dynamo, I must be increased, and it is seen readily enough that the load is proportional to I if E remains constant, or since I is inversely proportional to R, the resistance of the circuit, the load on a constant potential machine is inversely proportional to the resistance of the circuit.

In a constant current machine I is constant and E must be

increased if EI, the load, is to increase. If E rises, and I remains the same, then R must increase according to Ohm's law. Hence the load on a constant current machine is proportional to E and to R. An increased load on constant current machines requires larger values of E and R; on constant potential machines it requires a larger value of I and a smaller value of R.

If E is to remain constant, the magnetization produced by the field coils must remain constant, or, in other words, the conductors on the armature must cut the same number of magnetic lines of force each second. If I is to remain constant and E is to increase, then a correspondingly greater number of lines of force must be cut each second.

The essential difference between the two types of machines then is that in one there is a nearly constant magnetic flux for all loads, and in the other there is a magnetic flux varying with the load. The two types of constant potential and constant current dynamos will be considered separately.

Characteristic Curves. A characteristic curve, as its name indicates, is one which shows the characteristics or peculiarities of the dynamo to which it belongs. Such a curve is obtained by plotting the corresponding values of volts and amperes of the dynamo at different loads. The data for such a curve are obtained by taking simultaneous readings of current and voltage at various loads while the dynamo is in operation. Upon a piece of cross-section paper the amperes are plotted as abscissæ and the volts as ordinates; that is, the number of amperes of one reading are laid off horizontally from the lower left-hand corner, called the origin, covering as many divisions as there are amperes; and from this point a distance is laid off vertically, covering as many divisions as there are volts corresponding to that number of amperes. The point thus obtained is a point on the curve. The remaining readings are laid off in like manner, obtaining a number of points; a smooth curve through these points gives the desired characteristic.

A number of very important properties of a dynamo may be shown by means of the **characteristic curves.** These same characteristics may generally be figured out mathematically, but it is more correct and more satisfactory to get at the results from a practical test of the finished machine, as a general

rule. These characteristic curves explain the actions and possibilities of a dynamo in very much the same way that the indicator card of a steam engine gives its desired information. By drawing the characteristic curves to some known scale, the horse-power at which the dynamo will work with the greatest efficiency can be calculated.

Having drawn the characteristic curve of a machine to some particular scale, and knowing either the current, I, or voltage, E, at which the dynamo is working, the other value may be read off the curve directly. The value of the current, multiplied by the corresponding voltage, gives the output of the machine in watts, and this divided by 746, the number of watts corresponding to 1 horse-power, gives the output of the machine in horse-power.

It is possible to plot horse-power curves on the same paper with the characteristic curve (see Fig. 3), since horse-power $= \frac{\text{volts} \times \text{amperes}}{746}$. Any combination of amperes $\times$ volts which will give 746 is equal to 1 horse-power; thus 74.6 amp. $\times$ 10 volts $=$ 1 horse-power. Evidently, then, there is an infinite number of points the product of whose co-ordinates equals 746, and a line drawn through these points is a curve of 1 horse-power. If the characteristic of the dynamo cuts the curve at any point, it means that at that point the dynamo is furnishing 1 horse-power of electrical energy. It follows at once that curves may be similarly drawn for 2, 3, 4, or any number of horse-power. Then a glance at the characteristic curve will reveal at once what the activity of the dynamo is.

THE SERIES DYNAMO.

After the invention of the magneto machine with its permanent steel magnet, it was not a very great step to put coils of wire on the field magnets, and cause the current, as it comes from the armature, to pass through them before being led to the outside circuit, thus obtaining self-excitation (see Fig. 1).

A machine so connected is called a **series dynamo** because all its conducting parts are in series with one another. The properties

of this machine can be best explained by considering its characteristic curve. Every individual machine will of course have a curve differing somewhat from those of other machines which are differently proportioned, but the same general features will be present in the curve of all series dynamos. There are three characteristic curves possible for every dynamo, the **external,** the **internal** and the **total.** The distinction is as follows: the electromotive force generated by the machine is used up in two ways; in forcing the current through the resistance of the outside circuit, and in forcing it through the internal resistances of the dynamo itself. Therefore the voltage measured by a voltmeter applied to the terminals of the dynamo is the voltage which is forcing the cur-

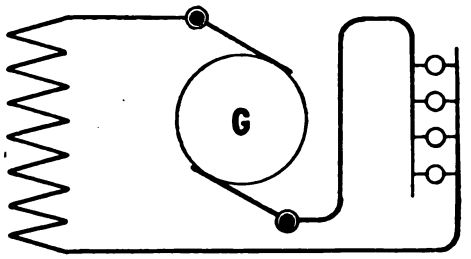


Fig. 1. Diagram of Series-Wound Dynamo.

rent through the outside circuit. This voltage is given by the lower curve in Fig. 2, which is called the **external characteristic.** To get the total electromotive force generated by the machine it is necessary to multiply the current by the internal resistance and add the result to the voltage measured at the terminals. The upper curve in Fig. 2 gives the total E. M. F. and is called the total characteristic. A characteristic curve is external, internal, or total according as the volts plotted against the amperes are the volts measured at the terminals, the volts lost in the armature, or the total volts. From the series characteristic curve shown in Fig. 2 it is evident that when the circuit is open and there is no current, there is no voltage generated by the machine. With the current equal to zero, the strength of the field due to the field magnets is zero. Were there any permanent magnetism remaining in the iron as there generally is, there would be a slight electromotive force generated, and the curve would

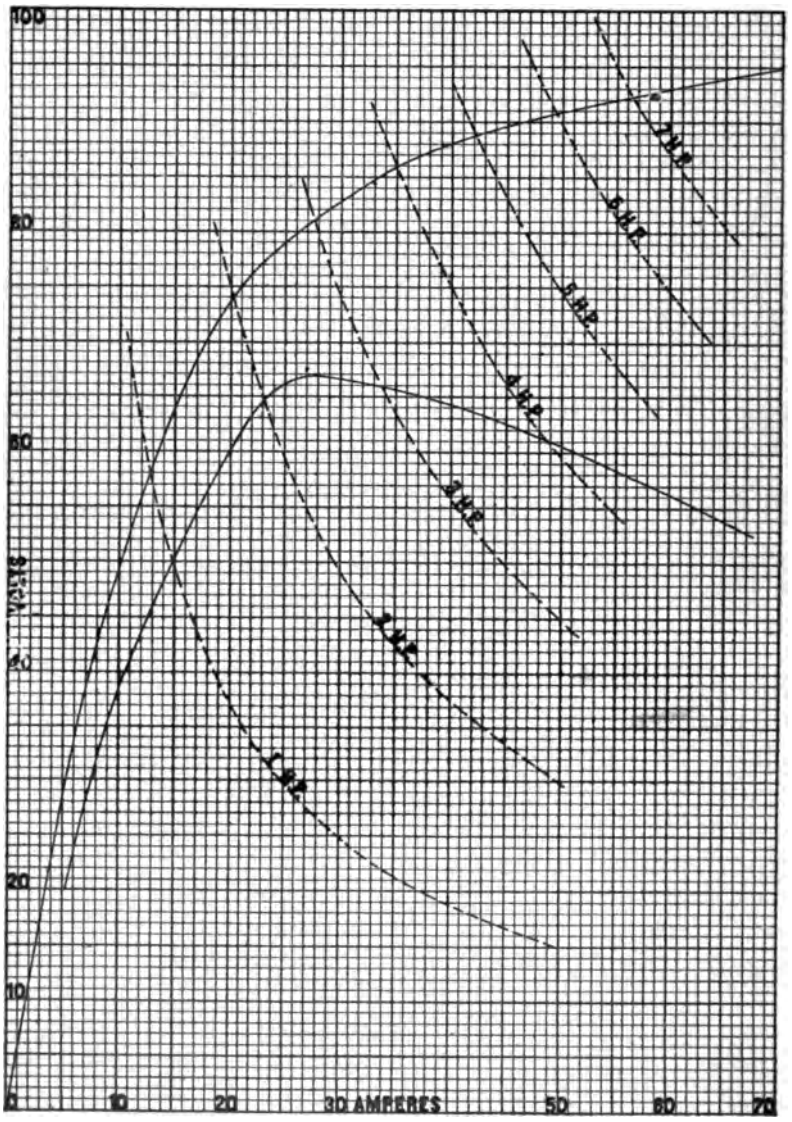


Fig. 2. External and Total Characteristic Curves of Series Dynamos.

not start at zero but a little way up on the scale. A dynamo with no magnetism whatever could not be made to take a load, or *build itself up* as the action is called. The curve runs up very steeply and approximately in a straight line, since the field, and consequently the electromotive force, increases with the increase in the current. This action goes on until the iron approaches saturation, or the point where it cannot take up any more magnetism. As it nears this point the curve bends over more and more, though still rising, until the actual point of saturation is reached. Beyond this point any increase in current cannot increase the strength of the field much and another factor becomes of importance, namely, the armature reaction. The increase in current must of course increase the armature field which tends to weaken the field due to the field magnets and consequently the voltage of the machine. It should be understood that the field of the armature does not actually exist because it is overpowered by the field magnets; it would exist were the field magnets absent and the current maintained by some external means. Its effect is to distort and weaken the field due to the field magnets. Beyond the saturation point therefore, any increase in current cuts down the field and consequently the electromotive force generated in the armature, provided the speed remains the same.

There is a very interesting property of series dynamos, which is best explained in connection with the characteristic curve. There is for every series dynamo a certain value of the current called the *critical current* at which the machine is unstable. Any increase in the circuit resistance tending to decrease the current below this value will result in the complete *unbuilding* of the machine and the consequent loss of load. Similarly the machine will not take a load or *build up* unless the resistance of the circuit is low enough so that the current can reach the critical value.

An examination of the characteristic curve shows that at a point a little more than two thirds of the way up to the maximum value of the curve, any decrease in the current of the machine decreases the voltage much more rapidly than is the case at any point higher up. This large decrease in voltage still further decreases the current, which result reacts on the voltage again, and this process goes on until the machine is completely unbuilt.

Total and external characteristic curves of a small Wood arc light dynamo are shown in Fig. 3. The total voltage generated by the armature is equal to the voltage observed at the terminals plus the lost voltage of the armature and series coils.

This was calculated by the equation

$$E' = E + I\,(r_a + r_{se})$$

where r_a was 5.4 ohms and r_{se} was 6.83 ohms.

The observed voltages are corrected for a speed of 1150 revolutions.

The electrical efficiency for this machine was calculated and found as follows:

DATA FOR EFFICIENCY OF SMALL WOOD DYNAMO.

E	Speed	I	$E'\ I'$	$E\ I$	$\frac{E\ I}{E'\ I'}$
88	1150	1	100	88	88 %
298	1150	4.4	1548	1311	84.7%
310	1150	4.6	1684	1426	84.6%
372	1150	6.0	2670	2232	83.5%
402	1150	7.0	3413	2814	82 %

The usual use of the constant current dynamo is for arc lighting. Arc lamps are commonly run in series and require about 10 amperes, and a potential of about 50 volts across the terminals of each. To maintain a constant current in the circuit the E. M. F. at the brushes of the generator must then increase 50 volts as each lamp is thrown in.

Constant current dynamos are series wound. Of such machines, we know that with a variable resistance in the external circuit, the current, or E. M. F. or both will vary. In the case of a machine supplying a certain current, if the resistance is increased the current strength will fall, and the field coils being in series the magnetic field is weakened, thereby lowering the E. M. F. and still further lessening the current. On the other hand if the external resistance is reduced, a larger current flows and a correspondingly higher potential is generated. Obviously, if such a machine is required to give a constant current through a

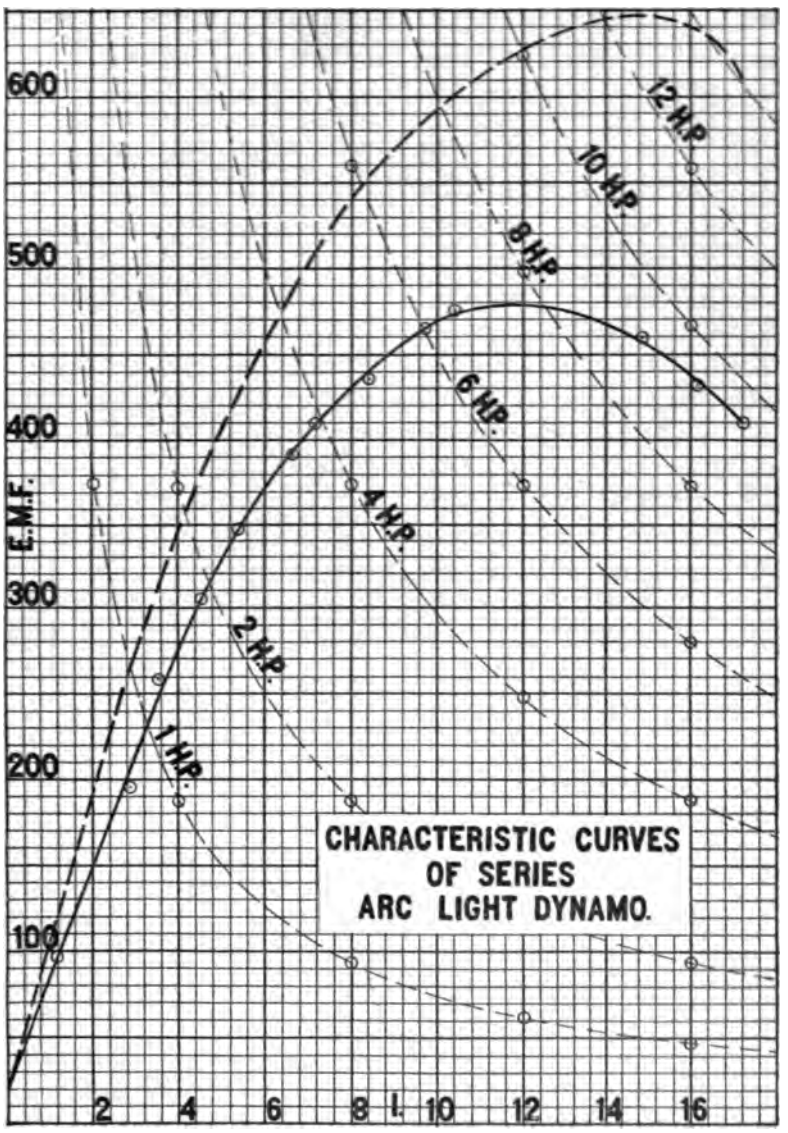

600
500
400
300
200
100
E.M.F.
12 H.P.
10 H.P.
8 H.P.
6 H.P.
4 H.P.
2 H.P.
1 H.P.
CHARACTERISTIC CURVES
OF SERIES
ARC LIGHT DYNAMO.
2
4
6
8
10
12
14
16

Fig. 3.

variable resistance, there must be some means provided for raising and lowering the E. M. F.

For effecting such regulation there are these three methods: (1) Varying the speed. (2) Varying the field strength. (3) Changing the position of the brushes.

The first method is seldom made use of although in principle it is very simple. There must be an automatic regulation of speed and the E. M. F. of course rises and falls with it. Such regulation, on account of the inertia of the heavy moving parts of the engine and generator, is too slow for lighting service.

Regulation by the second method is obtained either by changing the number of active conductors in the field or by changing the connections of the coils from series to parallel and *vice versa*. Running on light load (few lamps in series) only enough turns in the field are left in circuit to maintain a current of 10 amperes, and as more lamps are added to the circuit more field turns are thrown in to strengthen the field and to raise the voltage. The disadvantage of this method is the small range of loads that can be economically carried. For as the field coils are thrown in the cores soon rapidly approach the point of saturation, beyond which a large increase of ampere-turns effects the E. M. F. very slightly. On the other hand the machine will not run well on very light loads, for the current being constant the reaction of the armature is constant and on the weakened field has a greatly increased effect of distortion upon the field and causes serious sparking at the brushes.

The third method, that of shifting the brushes, is the most common one. To understand the principle of this regulation it will be well to refer back to the figure showing the two paths of the current through a ring armature and out by the brushes (see illustration in section devoted to "Theory of Dynamo-Electric Machinery"). It will be seen readily that the maximum E. M. F. at the brushes is obtainable when they are at the neutral point, that is when all the amature coils on either side of the brushes generate an E. M. F. in the same direction. If the brushes are shifted from the neutral point then some of the coils on either side oppose the others on the same side and a reduced pressure at the brushes is the result. If the brushes were placed at points midway between the neutral

points, then on each side half the coils would oppose the other half, and the pressure at the brushes would be nil; that is, the algebraic sum of the E. M. F.'s of the coils in each half would be zero. Then by moving the brushes from this point toward the neutral point, this sum, or the E. M. F. of the machine, would increase gradually to the maximum. Such is the principle of this method of regulation.

A constant current machine running on light load will have its brushes in a position considerably off the neutral point, and as more lights are thrown into the circuit, making the load heavier, they will be brought correspondingly nearer, maintaining sufficient E. M. F. at the brushes to force a current of constant value through the increasing external resistance. The shifting of the brushes is done automatically by electro-magnets in circuit, which act instantly to counteract any change of current strength flowing through them.

In practice various devices are used by different makers to accomplish the regulation. In some machines the position of the brushes on the commutator is altered by a mechanism controlled by the current; in others the controlling mechanism alters the field strength by short-circuiting some of the coils, or by increasing or decreasing a resistance placed as a shunt around the field, thus varying the value of the current in the field coils instead of the number of turns. The variable brush method is sometimes combined with the variable field method. A description of some forms of arc lighting machines, together with their regulators, is given in a following section.

Saturation Curve. To obtain a certain magnetization by a field coil, it is immaterial whether the coil consists of a small number of turns carrying a large current, or of a large number of turns carrying only a small current. As long as the product of the number of turns and amperes passing in them, or **ampere-turns**, is the same, the magnetization produced will be of constant value. Thus a coil of 100 ampere-turns may be made up of one turn of a large heavy wire carrying 100 amperes, or it may be made up of 100 turns of fine wire carrying one ampere, and the magnetizing force which will be exerted will be exactly the same in either case. Magnetizing forces are therefore sufficiently ex-

pressed by the number of ampere-turns in the magnetizing coil.

The saturation curve of a dynamo shows to what intensity the field magnets have been magnetized, and thus whether they are properly designed. The curves are formed by plotting points whose abscissæ are values of ampere-turns in the field coils, and whose ordinates are the corresponding values of the voltage, these points being plotted for varying values of the current. The readings may be observed for both ascending and descending values of the current, thus showing the effects of hysteresis.

From an economical standpoint it is best not to carry the magnetic flux too near the point of saturation during normal working, for the number of ampere-turns required to produce a given magnetic flux is greater in a saturated field than in one not saturated. In certain types of machines, however, there are certain advantages in practical points of working and regulation to be derived from having saturated fields that are of such importance as to outweigh the value of greater efficiency. By knowing from the type and the design of a machine to what degree its fields should be saturated, and by having an experimental saturation curve of the machine, a comparison can be made between the ideal and the result. Fig. 4 gives the saturation curves of the magnetic circuit of a Crocker-Wheeler dynamo for no load and with load, and for increasing and decreasing values of the current, the dynamo running at a constant speed of 1,620 revolutions per minute. The total characteristic curve of the simple series dynamo is only a slightly modified saturation curve, as will be seen from a comparison of Fig. 2 and Fig. 4. But in dynamos provided with regulators, the operation of these appliances changes the form of the characteristic very markedly.

THE SHUNT DYNAMO.

The shunt dynamo is so named because the coils which excite the field, instead of being connected in series with the outside circuit, form a shunt about it, the field circuit and outside circuit being connected in parallel at the brushes (see Fig. 5).

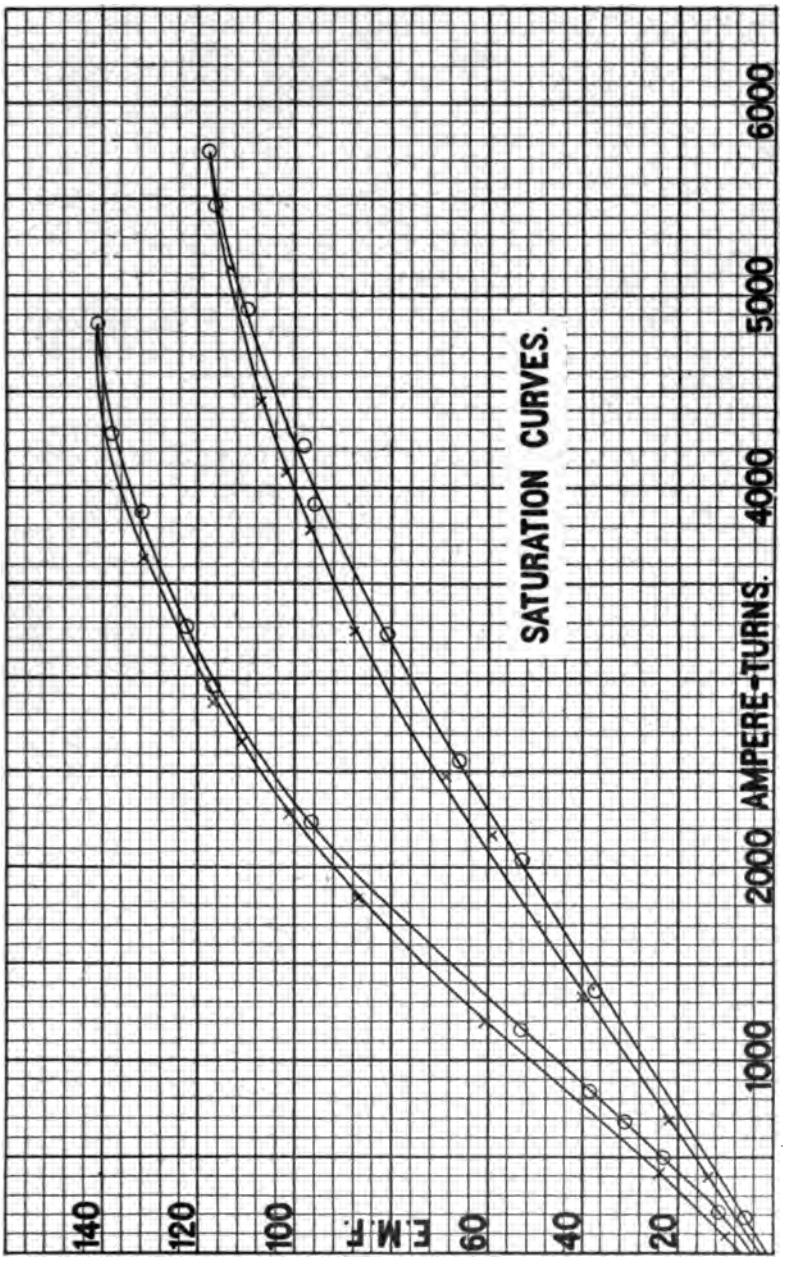

SATURATION CURVES.
E.M.F.
140
120
100
60
40
20
1000
2000
AMPERE-TURNS.
4000
5000
6000

Fig. 4.

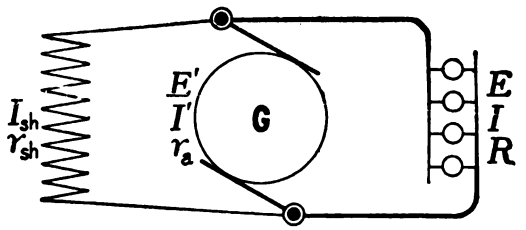


Fig. 5. Diagram of Shunt-Wound Dynamo.

As in the case of the series dynamo, the properties of the shunt machine can be best explained with the aid of characteristic curves (see Fig. 6). There are three characteristic curves to be considered, the **external,** in which the volts at the terminals are plotted against the amperes in the outside circuit, the **internal,** in which the volts at the terminals are plotted against the amperes in the shunt circuit, and the **total** in which the total volts generated by the machine are plotted against the total current. The total characteristic differs from the external only in that the volts are obtained by adding to the volts at the brushes the drop in potential through the armature. This drop in volts is equal to the current passing in the armature multiplied by the armature resistance. The total current is obtained by adding the current in the shunt circuit to that in the outside circuit. The internal characteristic taken with the outside circuit open is like the curve for a series dynamo. It rises steeply at first and then bends over as the saturation of the magnets begins to be noticeable. In fact with the outside circuit open the machine is a series dynamo with all its circuit in the field coils.

The external characteristic curve is a loop. It begins at maximum voltage and zero current, and extends almost horizontally at first, then slopes down more and more, turns rather suddenly, then doubles back and tends to approach the origin. When the dynamo is started the outside circuit is open and there is no current through the armature. As soon as it is built up the armature is generating only the current for the field coils which, as we have seen, is very small owing to the great resistance of these coils. But the small current produces only an insignificant drop in the armature so that the voltage at the brushes is nearly the total generated by the armature. Hence the current in the field coils is as great as it can ever become which makes the field magnetism and consequently the E. M. F. generated by the armature a maximum. Now suppose that a number of lamps (connected in

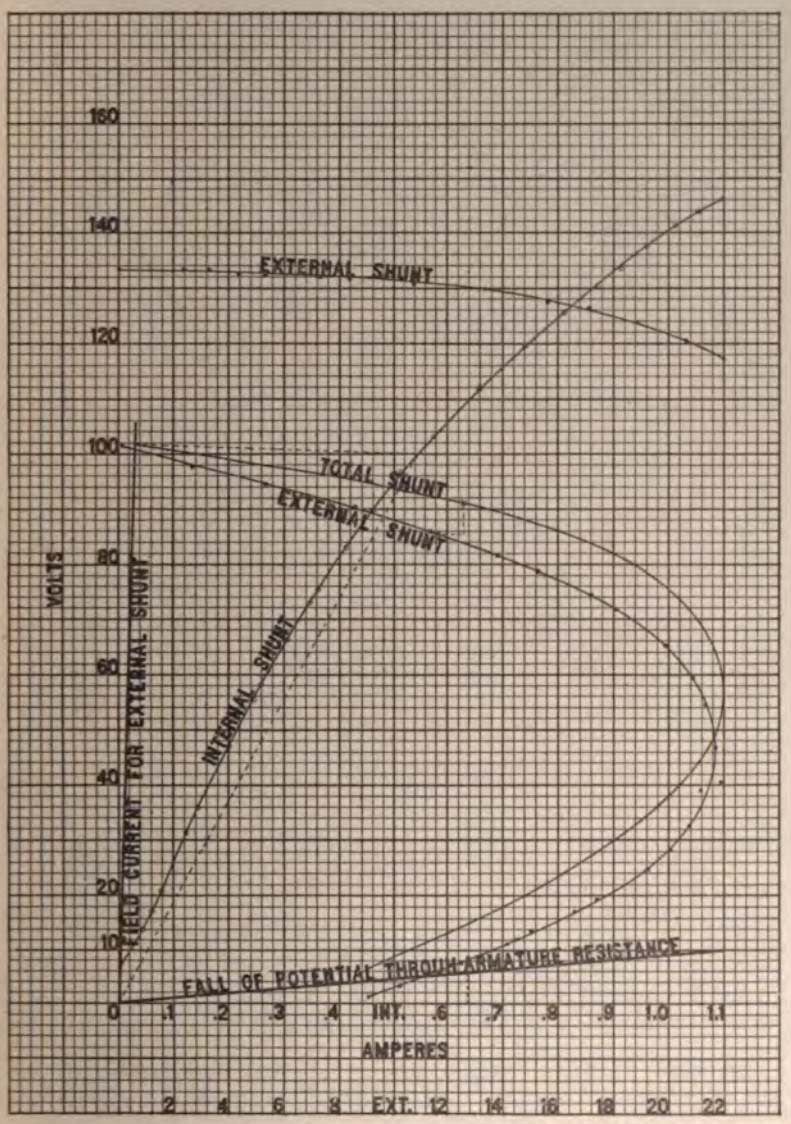
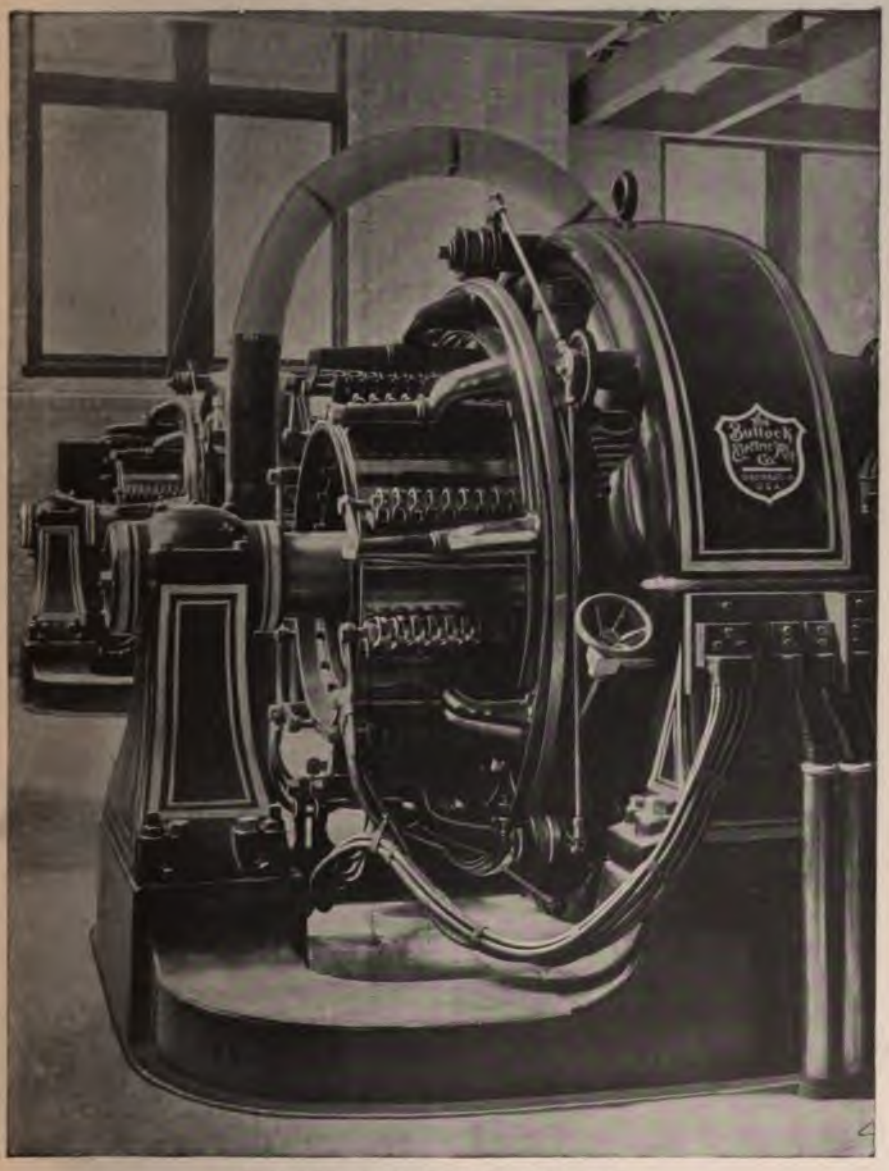


Fig. 6. Total. External and Internal Characteristic Curves of Shunt Dynamo.

parallel across the leads from the machine) are thrown on the machine. A current flows at once, and as a result there is a drop through the armature so that there is a little less voltage available at the brushes to excite the field coils, which means a slight dropping of the total voltage. If more lamps are connected in parallel, the existing voltage at the terminals will act for an instant, and furnish them with as much current as those already on are receiving, but the greater current means increased drop in the armature which, as explained above will again bring down the total voltage generated. With less voltage at the terminals the total current will diminish a little. Therefore lowering the resistance of the circuit by the addition of lamps in parallel lowers the available voltage, because it increases the amount of the volts lost in the armature. By building the armatures with an extremely low resistance it is possible to make machines for which the drop in terminal pressure is not very noticeable over quite a large range of load. It is for this reason that a shunt machine is used for incandescent lighting where it supplies an approximately constant voltage. The dynamo would be designed for such a voltage that at low loads the voltage would be a little too high while at heavy loads it would be a little too low. In actual lighting work, however, the resistance of the field coils is made somewhat less than would be necessary to give the right voltage. This is accomplished by using a larger size of wire than necessary, the number of turns remaining the same.

By inserting a **rheostat**, or resistance which can be varied at will, between the field coil and one of the brushes, the current in the coil can be cut down to the proper value under normal conditions, and when the load increases and the effective voltage tends to drop, it is only necessary to cut out some of the resistance in the rheostat to obtain more current, and consequently greater excitation in the field coil, thereby raising the voltage to its normal value again. The rheostat (see Fig. 7) consists generally of a resistance with connections at short intervals along it and terminating in metal contacts arranged in a circle. A sliding contact piece is moved over them by the handle, introducing the current at any point on which the sliding contact is resting. In this way the amount of resistance in series with the field coil may be regulated with great exactness.



250 K.W. ENGINE-TYPE GENERATOR

at Prudential Life Building, Newark, N. J.

Bullock Electric Manufacturing Co.

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ASTOR, LENOX
TILDEN FOUNDATIONS

This regulation is generally effected by hand, the resistance being decreased when the voltmeter shows that the voltage is falling on the line, and vice versa. By means of regulators, magnets, solenoids and various electrical and mechanical means this regulation is sometimes made automatic.

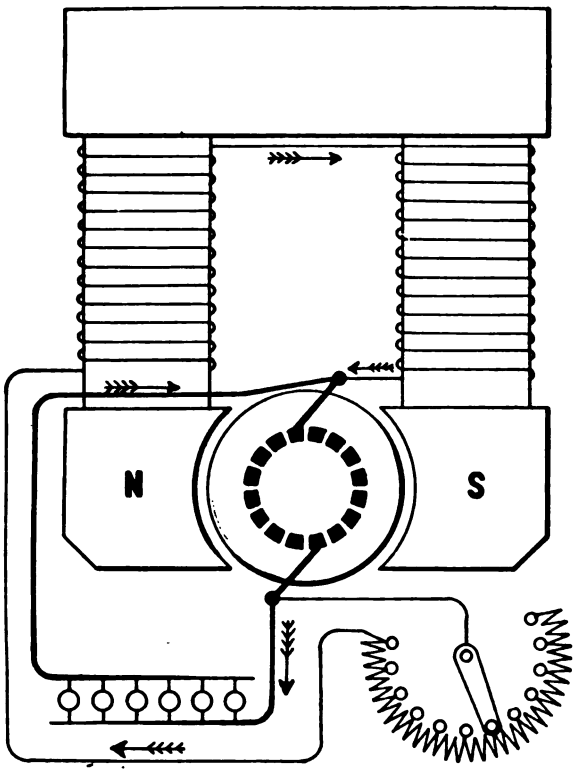

Fig. 7. Dynamo and Rheostat.

Returning to the characteristic, it is interesting to note that the continued increase in load on the machine, due to decrease of external resistance, causes the voltage to fall more and more rapidly until a point is reached where a decrease in circuit resistance can throw no more load on the machine, because the decrease in voltage is so rapid as to unbuild the machine. Theoretically the curve would come down to the origin; it does not, practically, however, owing to residual magnetism.

The resistance of the outside circuit corresponding to any point on the characteristic curve can be found very readily. The voltage divided by the current gives the resistance. By drawing a straight line (see Fig. 8) from the origin or the point where the current and voltage are 0 through the point corresponding to 50 volts and 50 amperes it will intersect the characteristic curve at a certain point. It is obvious from the figure that the voltage at this point just equals the current, and so the resistance here is 1 ohm. Similarly by drawing a line from the origin through the point where voltage is 100 and current 50 the characteristic curve is intersected at another point and the resistance of the circuit at this point is 2 ohms. A scale of resistance may be marked on the vertical line corresponding to 10 amperes. By drawing a line from any point on the characteristic curve to 0, the point of intersection on this resistance scale line gives the resistance of the outside circuit. The characteristic curve shown in Fig. 6 is for a small shunt dynamo which being run at 630 revolutions gave a maximum of a little less than 2 horse-power at 68 volts and 19.2 amperes. With a decrease in resistance much below $2\frac{1}{2}$ ohms the current increases but little, whereas the voltage falls a great deal. If the external resistance becomes less than 1 ohm the machine loses its voltage and current immediately and will not build itself up again until the resistance is increased. The most critical part of this curve is where the voltage is about 30 or 31 and any given change of resistance at this point will alter the voltage more than at any other part of the curve. By increasing the resistance the voltage is steadily increased until it gets to its maximum when the external circuit is open and the resistance is infinite, the whole voltage being then available for magnetizing the shunt field coils to their maximum strength.

Fig. 8 shows the characteristic curves of a shunt-wound Gramme dynamo capable of giving 400 amperes at 120 volts. The armature conductors were not capable of carrying more than 400 amperes, and the part of the curves not actually found by experiment is shown in dotted lines. The lower curve marked E is the external characteristic while the upper curve marked E' is formed from it by adding to the external voltage at any point the corresponding value of the voltage lost in the armature at the given time.

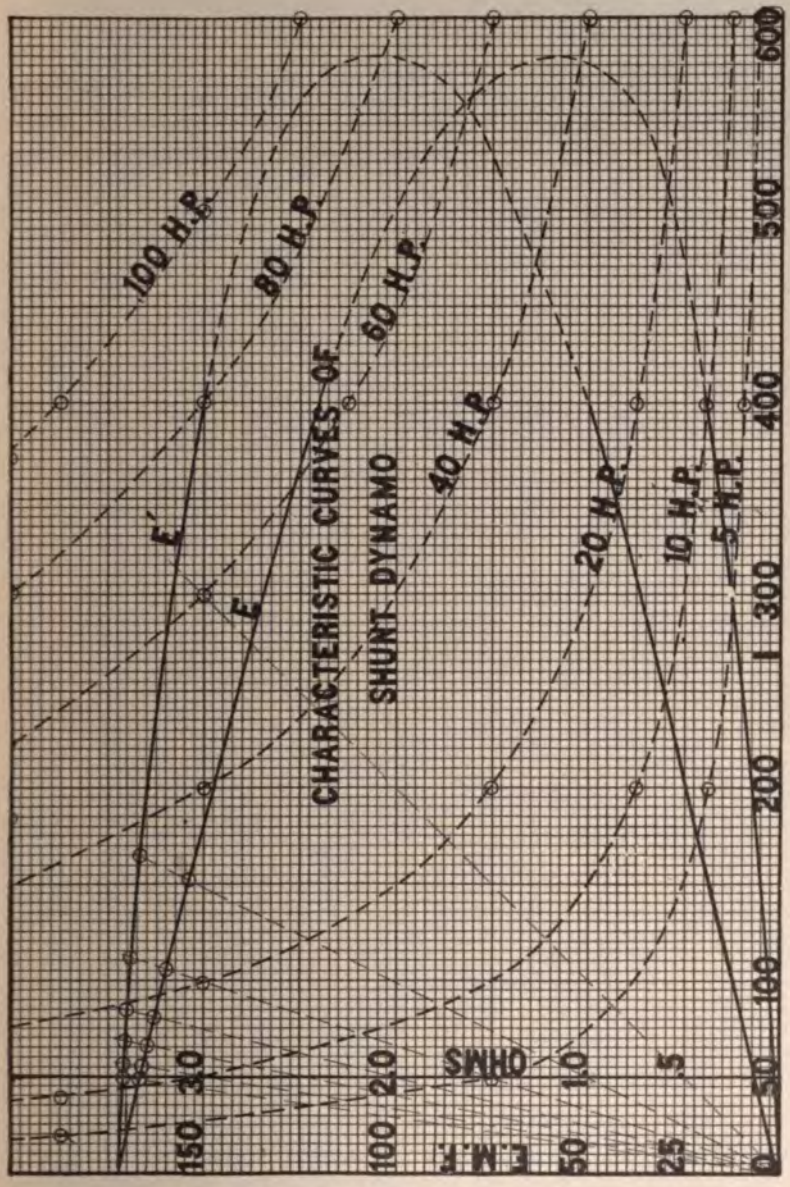

Fig. 8. Characteristic Curves of Shunt-Wound Gramme Dynamo.

Both series and shunt machines have critical points, but the series machine will act only with the resistance of the circuit less than a certain amount while the shunt machine will work only with it greater than a certain amount. With the series machine, increase in the number of lamps in series decreases the ability of the machine to maintain its load, increase in the number of lamps in parallel increases the ability of the machine to generate and consequently increases the current per lamp. With the shunt machine an increase of the lamps in series increases the ability of the machine to furnish current, while increase in the number of lamps in parallel decreases the ability of the machine to supply current. These opposing characteristic qualities are made use of to secure a machine which is automatic in its ability to furnish a constant potential under widely varying loads.

THE COMPOUND DYNAMO.

Electrical energy for incandescent lights, power circuits, and railways is supplied by constant potential dynamos, that is by machines which are so constructed that they will deliver current varying in amount between zero and the limit of their capacity and at the same time maintain a pressure at the terminals that is very nearly uniform.

Though a shunt machine comes nearer to fullfilling the requisite conditions than a series, still neither are self-regulating. The shunt machine with a variable resistance in series with the field coils, has been used as described on a previous page. There are also other arrangements which could be used to attain the same end but as they have not found favor in practice they will not be considered here.

It has been shown how with the shunt machine, owing to increase in current, the volts lost in the armature are increased, resulting in decreased ability to sustain the output. To make a shunt machine self-regulating some means must be provided for increasing the field strength with the increase of the strength of the current. This can be easily accomplished by winding on the field magnets a coil consisting of a few turns of heavy wire through which the whole current of the circuit can be passed. This series coil is sometimes called the compensating coil because it compen-

sates for the weakening tendency when the shunt coil alone is used. A machine with such a winding is called a **compound-wound machine.** Being a combination of the series and shunt machines, its characteristic curve is a combination of the two, the

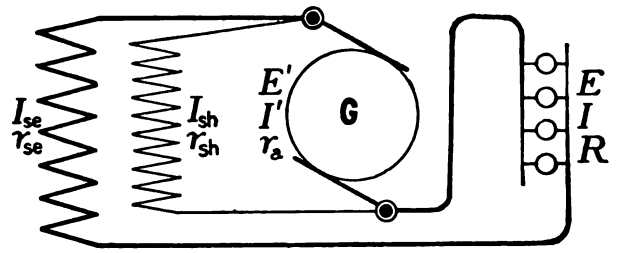

Fig. 9. Ordinary, or Short Shunt Compound Dynamo.

rise in the characteristic of the series machine occurring at the point where that of the shunt machine decreases.

There are two methods of connecting up a compound-wound machine, called respectively **short shunt** (see Fig. 9) and **long shunt** (see Fig. 10), according as the shunt terminals include the armature, that is, connected from brush to brush, or the series coil in addition, that is, connected from brush to end of series coil. It

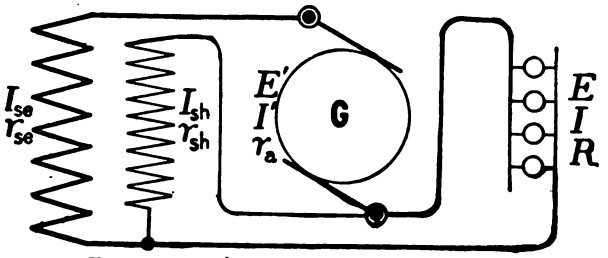

Fig. 10. Long Shunt Compound Dynamo.

makes very little difference in practical results which form of connection is employed, since the resistance of the series coils is always very small. The characteristic curve of a compound machine generally approaches a horizontal line, often it rises slightly at the beginning and then continues nearly horizontal throughout the range of loads that it is required to carry.

As the load increases and the resistance of the outside circuit decreases the main current in the series field coils increases and the current in the shunt coils still remains constant as it is now fed with a constant voltage. Thus although there are more lost volts in the armature to cut down the voltage, and although there is a much greater demagnetizing effect produced by the armature yet the voltage supplied to the external circuit is still maintained constant. A compound dynamo therefore if properly proportioned, will supply a practically constant voltage at all loads. In the case of the ordinary or short shunt compound dynamo, the potential at the brushes is kept constant. In the case of the long shunt dynamo the potential at the terminal of the working circuit is constant. The latter arrangement therefore is somewhat preferable but either arrangement proves satisfactory in well designed dynamos as the actual value of the difference in the two cases is generally very slight.

In the case of the ordinary or short shunt compound dynamo the series coils furnish the excitation required to produce a potential such as will compensate for the lost voltage in the armature and the demagnetizing effects due to the armature. In the case of the long shunt dynamo the series coils compensate for these same losses as well as for the lost voltage of the series coils.

It is advisable and generally customary to put a somewhat greater number of series turns on the field coils than is necessary to overcome armature reactions and lost voltage in order to have the dynamo give a somewhat greater voltage at full load than at no load. This process which is called **overcompounding** is calculated for a rise of voltage of about four or five per cent. As the load increases an engine often runs a few revolutions slower, or there is a trifle more slipping of the belt which causes the speed of the armature to drop a little; the increasing load is also accompanied by a greater lost voltage in the line or feeders; hence the dynamo should be overcompounded to make up for these losses. If the load is at some distance from the generator there might be considerably more than 5% drop of voltage at full load. This drop can be figured and a machine may be especially compounded for this loss at the time it is built. The object of course is to keep the voltage constant at the lamps, and if they are some distance

away and the load is constantly changing it is often necessary and advisable to run so-called *pressure wires* from the center of distribution back to a voltmeter in the dynamo room. Then if the dynamo is not overcompounded so as to give the proper pressure at all loads the pressure may be varied by adjusting the rheostat which is in series with the shunt coils of the dynamo. Even though the dynamo is properly compounded it is almost always necessary to regulate with the rheostat also in the case of incandescent lighting, especially where the lamps are distributed over a wide territory.

In designing a dynamo for any given output it is necessary to make due allowance for the total energy to be generated which is the total voltage E' multiplied by the total current I'. In order that the energy lost in the series field turns may not be too great, it is well to have them wound near the field cores so that each turn may be as short as possible and the shunt coils may be wound outside of the series turns.

In Fig. 11 are shown some characteristic curves of a compound-wound Crocker-Wheeler dynamo running at 1500 revolutions per minute.

The upper curve is the external characteristic of the dynamo running with all the resistance cut out of the shunt field regulating rheostat. It is running, therefore, with a maximum field excitation and giving its maximum voltage, about 127.8 volts at no load. It will be noted that as the load increases the voltage drops somewhat. It is evident that the magnetic flux due to the series ampere-turns on the field coil is not great enough to make up for the armature demagnetizing effects and the lost volts in the armature. Therefore there are not enough series turns, and the dynamo is undercompounded when running at 127.8 volts.

Next some of the resistance of the regulating rheostat is put in series with the shunt field until the voltage falls to 109.2 volts. By increasing the load the voltage increases, being from about 4 % to 7 % higher as the load increases than it was at no load. Now the rise in voltage, due to compounding, makes up for the loss in the line wires and is a little too great in the case of the 7 %, and in order to keep the lamps from burning too brightly the rheostat handle would have to be turned so as to cut the voltage down a little.

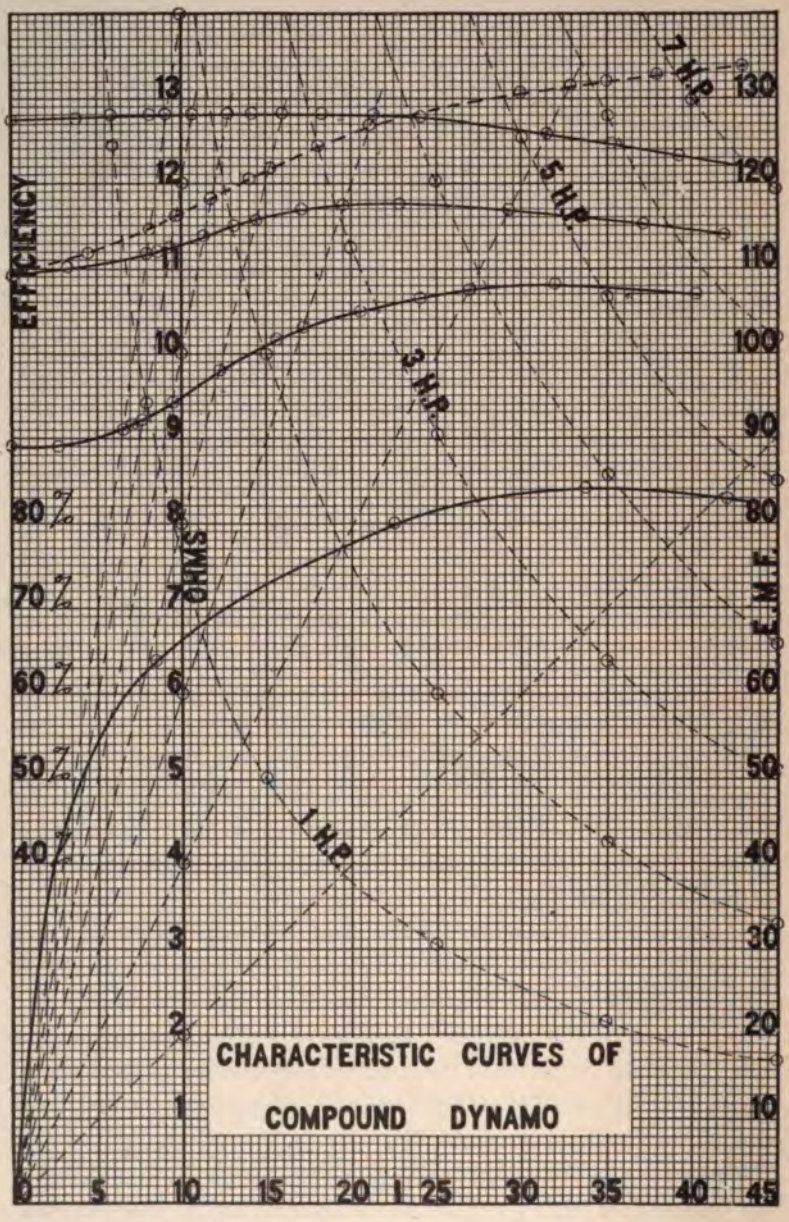

Fig. 11. Characteristic Curves and Efficiency Curve of a Crocker-Wheeler Compound Dynamo.

Judging from these two curves it appears that if the dynamo were run at a little higher initial voltage, say 112 or 115 it would be then running at just about the proper voltage for which it was compounded. The percentage of the overcompounding would then be about four or five per cent and the dynamo might run at varying loads with little or no need of adjusting the rheostat.

The curve shown by broken line (see Fig. 11) is the total characteristic curve derived by adding the values of the lost volts in armature and in series field to the value of the external voltage.

The lower compound characteristic curve starting with an initial voltage of 89 shows that the dynamo is very much overcompounded when running at this voltage. The rheostat has been so adjusted that less current flows through the field coils, the shunt current is reduced and the value of the shunt ampere-turns is reduced. On the other hand the value of the series ampere-turns is as great as formerly as the load increases, and so the value of the series excitation is now large in comparison with that of the shunt. The voltage therefore increases greatly with the load, causing the dynamo to be greatly overcompounded when started at an initial voltage of 89.

In Fig. 11, is also given a curve of commercial efficiency for this 5 H. P. Crocker-Wheeler compound dynamo, the commercial efficiency being the useful electrical work, $E\,I$, derived from the dynamo, divided by the value of the mechanical work delivered to the pulley of the dynamo.

The following table contains the data from which the characteristic curves shown in Fig. 11 were drawn.

I	E	I	E	I	E
0	127.8	0	109.2	0	89.
3.6	128.0	3.4	110.0	2.7	89.7
8.4	128.0	8.7	112.0	7.2	91.3
14.2	127.7	13.2	115.0	11.3	96.4
18.4	127.7	17.1	117.0	15.6	101.8
23.8	127.6	22.6	117.0	20.6	105.0
27.2	127.2	25.6	116.8	24.6	105.4
30.9	126.0	29.3	116.0	27.9	107.5
35.2	124.0	33.7	116.0	32.0	108.2
39.3	122.9	37.1	115.9	36.1	108.0
43.8	121.9	42.8	114.0	40.3	107.0
				40.4	107.0

The characteristic curves of a 5 K.W. Edison compound

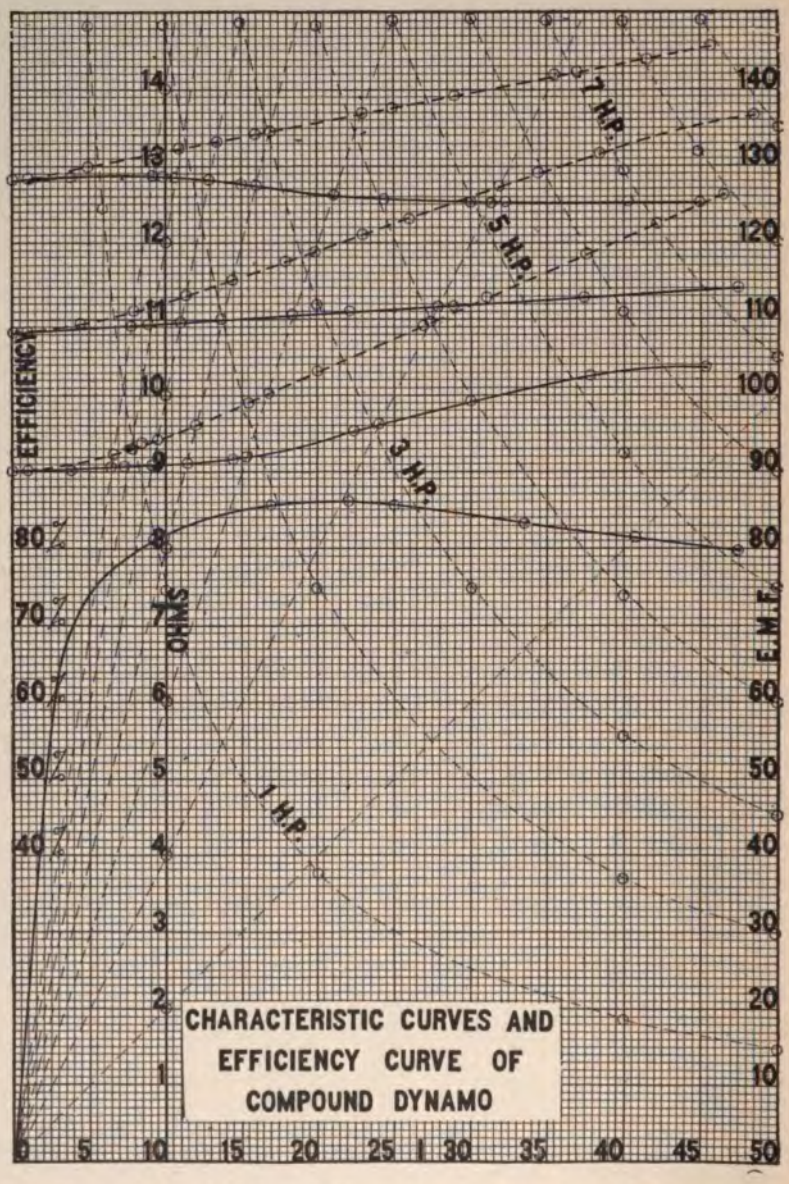

Fig. 12. Total and External Characteristic Curves and Efficiency Curve of 5 K. W. Compound Edison Dynamo.

dynamo are given in Fig. 12, for initial voltages of 131, 110, and 90, at a speed of 1,700 revolutions. In testing dynamos it is very difficult to keep the speed absolutely constant. There may be a variation in the speed of the main pulley from which the dynamo is run, and the belt may slip more and more as the load increases. However, as the voltage is proportional to the speed, the observed voltage may be corrected for the observed speed quite readily. The reading of the voltmeter and the tachometer should both be taken at the same instant.

The characteristics of the compound Edison dynamo as shown in Fig. 12, present very much the same phenomena as were exhibited by the characteristics of the Crocker-Wheeler dynamo in Fig. 11. The Edison dynamo, the curves of which are shown, is probably properly overcompounded for about 4% or 5% when running at an initial voltage of about 115. A curve of electrical efficiency is also shown.

The following table gives the data for the characteristic and efficiency curves of the 5 KW. compound Edison dynamo.

Speed.	E	E corrected to 1,700 rev.	I	Speed.	E	Corrected E	I	$\frac{E\,I}{E'I'}$
1740	131.5	128	0	1720	110	108.1	0	0
1725	130.0	128.1	3.8	1715	111	109.3	8.7	.82
1730	130.0	128.3	9.8	1690	111	111.0	22.0	.86
1725	128.5	126.7	14.7	1670	110	111.3	28.7	.87
1720	128.0	126.6	19.2	1665	112	113.1	37.3	.82
1715	126.5	125.4	24.3	1660	112	114.0	47.5	.80
1710	126.5	125.6	28.0	1730	91.5	90.0	.0	
1705	125.5	125.3	32.2	1730	91.5	90.0	7.4	
1685	124.0	125.2	36.0	1725	93.0	91.6	14.6	
1670	123.0	125.3	40.3	1715	96.5	95.7	22.4	
1665	123.0	125.6	45.0	1685	99.0	99.9	30.0	
1635	118.5	123.3	46.5	1660	99.5	101.9	38.0	
				1640	100.0	103.7	45.4	

THE MAGNETIC CIRCUIT.

Every dynamo-electric machine or electrical instrument whose working depends upon the laws of magnetic induction, must have a complete magnetic circuit just the same as it has a complete electric circuit. Moreover the laws governing the magnetic circuit are similar to the laws governing the electric circuit. The one important difference between the magnetic circuit and the electric circuit lies in the difference of materials of which the two

are composed. Every substance is a conductor of electricity to a certain extent; there is no perfect non-conductor or insulator. The best conductors are metals and graphite. Dry air, dry wood, mica, rubber, etc., are such very poor conductors of electricity that they are called insulators or non-conductors.

Almost all substances are fairly good conductors of magnetism. Iron and steel in their various forms are *excellent* conductors, and nickel, cobalt and oxygen lie between these and the fairly good conductors in their magnetic qualities. Fairly good conductors include solids, liquids and gases, metals and non-metals, organic and inorganic substances; and with the exceptions named above and a few others, they are *equally* good conductors. Air is generally taken as the standard and is neither a better nor a poorer conductor than gold or copper.

The greater the current in an electric circuit the greater is the amount of energy required to cause the current to flow, provided the resistance remains unchanged. In like manner the amount of energy required to produce a magnetic flow in air is proportional to the strength of the magnetic field produced. Iron and steel however have induction coefficients which are very important in their bearings. When an electromagnet is weakly magnetized the amount of electrical energy required is nearly proportional to the strength of magnetism. After the metal begins to be **saturated** with magnetic lines, the amount of electrical energy required to increase the magnetism becomes much greater than formerly. After the metal has become strongly saturated with magnetic lines even a large increase in the electrical energy supplied may produce almost no increase in the magnetic intensity.

In order to have an electric flux or electric current in an electrical circuit it is necessary to have an electromotive force. Similarly in order to have a magnetic flux or magnetic field it is first necessary to have a **magneto-motive force,** (M. M. F.). Lodestones and other so called permanent magnets have a magneto-motive force that keeps up a magnetic flux or field constantly. By passing an electric current through an electric circuit a magneto-motive force is induced at right angles to the path of the electric conductor. In the electric circuit a given E. M. F. will cause a larger current to flow through a low resistance conductor

than through a high resistance conductor. Similarly with a given M. M. F., a greater magnetic flux is produced in a good magnetic circuit of iron or steel than in a poor magnetic circuit of air or copper.

The geometrical distribution of the magnetic lines of force about a conductor carrying a current is shown in Fig. 8, which gives an end view of the conductor. The current is assumed to be flowing toward the observer, and the direction of the magnetic flux is shown by arrows. As shown by the flux paths 1, 2, 3, 4, 5, the magnetic density is greater near the wire, diminishing rapidly in strength farther from the conductor. The mathematical law of this diminution is as follows: **the intensity varies inversely as the distance from the conductor.**

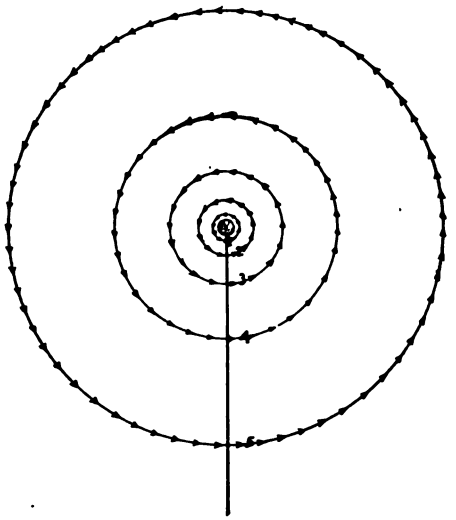

Fig. 8.

If an electric conductor is bent into the form of a loop and an electric current of one ampere passes through the conductor then a certain number of magnetic lines of force pass through the loop. After following curved paths they will return to the loop passing through it again in the same direction as at first. Now if two amperes flow through this conductor, or the same current (one ampere) flows through two similar conductors laid side by side, then in either case just twice as many magnetic lines will flow through the loop as in the first case. Therefore the intensity of the magnetic flux through a loop composed of an electric conductor carrying a current, depends upon and is directly proportional to the number of **ampere-turns.** This magnetic flux can be made very great either by forcing a large current through the conductor, or by having a very large number of turns in the loop, or by both.

The absolute unit of current being ten times the ampere, the ampere-turn is only one tenth the value of the current-turn. Of the two, the ampere-turn is in more common use as a practical unit. The fundamental unit of M. M. F. in the United States is called the **gilbert,** and is produced by $\frac{1}{4\pi}$ of a C. G. S. unit or current-turn, or by $\frac{10}{4\pi}$ ampere-turns. Therefore by dividing the number of ampere-turns in any coil by $\frac{10}{4\pi}$, the M. M. F. of the coil is obtained in gilberts.

The quantity of magnetic flux in any magnetic circuit depends upon the M. M. F. and upon the nature and form of the circuit. In an electric circuit the current produced by an E. M. F. depends upon the resistance of the circuit. Similarly in a magnetic circuit the magnetic flux produced by a M. M. F. depends upon the **magnetic reluctance** or simply **reluctance** of the magnetic circuit. Magnetic reluctance is similar to electric resistance and is often defined as *the resistance of a circuit to magnetic flux.*

The resistance of an electric circuit measured in ohms is equal to the **specific resistance** or **resistivity** of the conductor, multiplied by the length and divided by the cross section of the wire. Similarly, the reluctance of a magnetic circuit, measured in **oersteds,** is equal to the **specific magnetic resistance** or **reluctivity** of the magnetic conductor, multiplied by its length in centimeters, and divided by its cross section in square centimeters. The reluctivity of a vacuum is unity and the reluctivity of air is generally considered equal to unity although it varies slightly. All other non-magnetic substances such as brass, copper, glass, wood, and water also have a reluctivity which is practically equal to unity. The reluctivity of magnetic metals such as iron, steel, nickel, and cobalt vary quite widely from unity and their values also vary quite widely among themselves.

The unit of reluctance by which the magnetic resistance of a circuit is measured is called an **oersted,** and is defined as the reluctance or magnetic resistance of a cubic centimeter of air measured between two opposite faces, hence the reluctance of a

column of air 20 cm. long and 2 cm. square (4 sq. cm.) is 5 oersteds.

In the electric circuit,

Electric flux (in amperes) =

$$\frac{\text{Electromotive force (in volts)}}{\text{Resistance (in ohms)}}, \quad \text{or } I = \frac{E}{R}.$$

In the magnetic circuit,

Magnetic flux (in webers) =

$$\frac{\text{Magneto-motive force (in gilberts)}}{\text{Reluctance (in oersteds)}}, \quad \text{or } \Phi = \frac{\mathfrak{F}}{\mathfrak{R}}.$$

If a non-magnetic ring (see Fig.14), is uniformly wound with insulated wire, and a current is passed through the wire, the magnetic circuit will be completely closed by the coil or solenoid, and no magnetic flux will leak outside of the coil. If the cross section of the ring is 15 sq. cm., and the mean circumference is 45 cm., the reluctance of the magnetic circuit will be $\frac{45}{15} = 3$ oersteds. If the number of turns of wire is 100 and the current 5 amperes the M. M. F. in the magnetic circuit will be 500 ampere-turns, or $500 \div \frac{10}{4\pi} = 628.32$ gilberts. The magnetic flux in webers will be

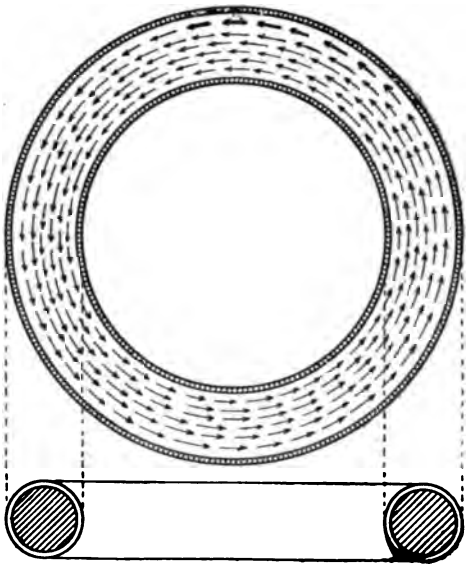

Fig.14.

$$\frac{628.32}{3} = 209.44 \text{ webers.}$$

The weber is the *magnetic line* of the preceding section.

The greater part of the magnetic circuits in dynamos consists almost entirely of iron. The reluctivity of iron and steel varies greatly, according to hardness and chemical composition, and also the degree to which it has been magnetized. When iron is fully saturated magnetically its reluctivity is as great as the reluctivity of air. The reluctivity of soft iron or steel, when it is not strongly magnetized, is often several thousand times less than that of air. The ferric magnetic circuit is an easy one to calculate, however, since the magnetism is confined almost exclusively to the iron, thus giving a magnetic circuit of definite and easily computed length and cross-section.

There is some leakage of magnetic flux from the iron into the air. For dynamos of ordinary sizes and shapes it varies from 15% to 30% of the flux through the field coils. It may be separately calculated and allowed for.

The **magnetizing force**, represented by the symbol $\mathfrak{H}$, may be defined as the rate at which the magnetic potential diminishes in a magnetic circuit. The total fall of magnetic potential in a magnetic circuit is equal to the M. M. F., just as the total fall or drop of electric potential in an electric circuit is equal to the E. M. F. The total difference of magnetic potential in the magnetic circuit shown in Fig. 14 is 628.32 gilberts. As this circuit is symmetrical and uniform throughout, the drop of magnetic potential is uniform and equal for each unit of length. The mean length of the circuit being 45 cms., the rate of fall of potential is about 14 gilberts per centimeter all around the circuit. This is the magnetizing force, or the magnetic force, represented by $\mathfrak{H}$. When there is no iron or other magnetic substance in the circuit, the value of the magnetizing force $\mathfrak{H}$ is equal to the flux density $\mathfrak{B}$.

If in any magnetic circuit the M. M. F. expressed in gilberts is divided by the length of the magnetic circuit in cms., the average value of the magnetizing force will be obtained. Thus in a long helix, if there is a M. M. F. of 500 gilberts, and the magnetic circuit inside the helix has a length of 50 cms., the magnetizing force will be 10 gilberts per centimeter, and the flux density will be 10 gausses, provided there is no magnetic substance in the circuit.

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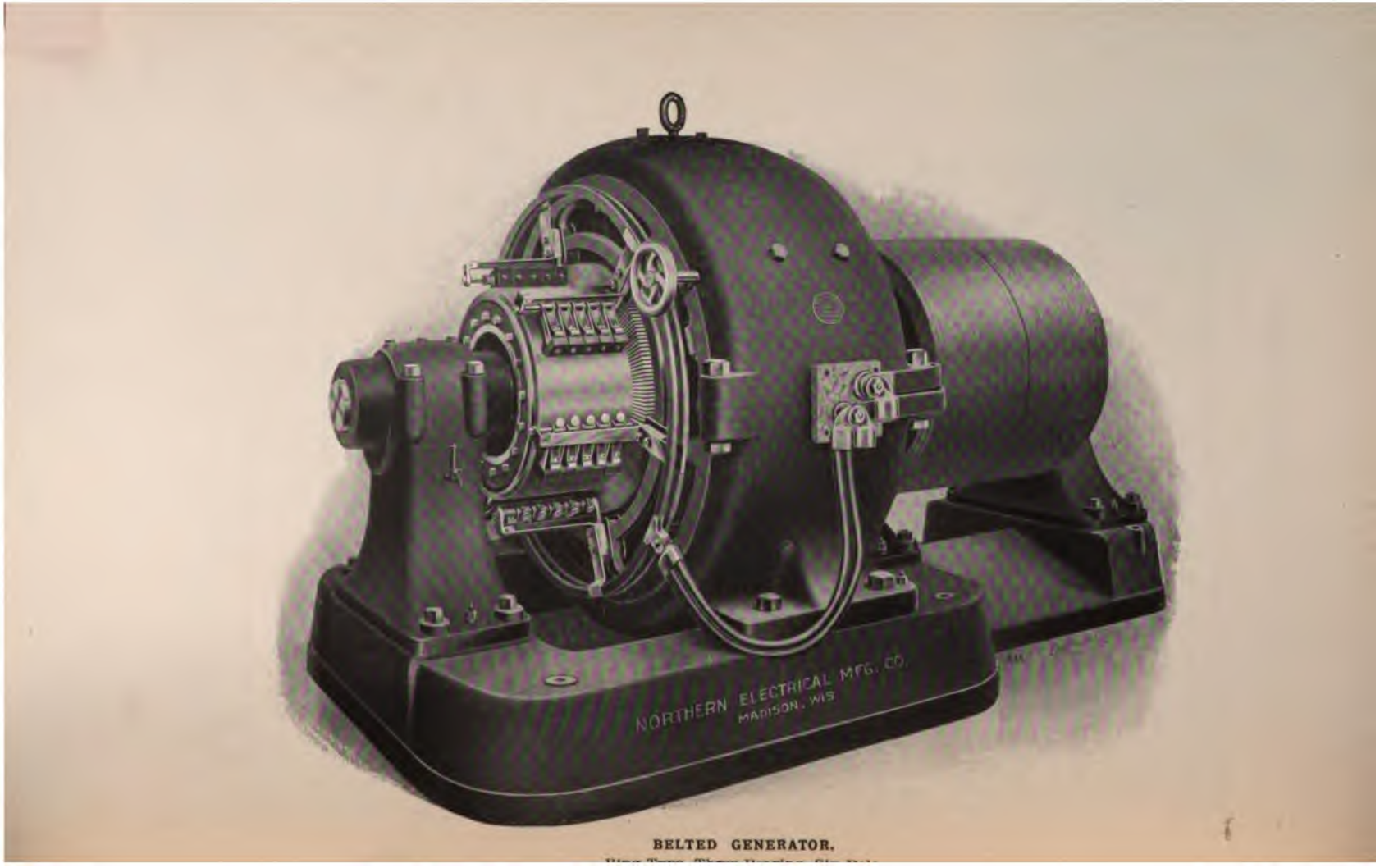


BELTED GENERATOR.

If there is iron or any other magnetic substance in the circuit the magnetizing force will still remain 10 gilberts per centimeter although the magnetic flux density will be greatly increased according to the permeability of the magnetic circuit.

FORMS OF FIELD MAGNETS.

The function of the field of a dynamo is to provide a space filled with lines of magnetic induction which the conductors of the armature may cut, thus causing an electromotive force to be generated in them. It is immaterial to the generation of an electromotive force whether the armature or the field revolves, though generally the field is stationary. It is usually desirable to maintain the magnetic induction or number of magnetic lines at constant value. The first field magnets to be used were permanent steel magnets, and small dynamos are still built with them. The magneto-machine is a shuttle-wound dynamo having its field produced by permanent magnets. Such machines can not, of course, have as large a capacity as others equipped with electromagnets, and they are subject to loss of magnetism which after a while is liable to render them useless unless they are remagnetized. The fields of modern dynamos are supplied by electromagnets, connected to the circuit of the dynamo according to the purpose for which it is built. The different forms, named according to the winding are, — the magneto, the separately excited machine, the series machine, the shunt machine and the compound-wound machine.

The separately excited dynamo has its field coils fed from some outside circuit. This form of winding is not used much with direct current machines except for special cases. Its place is with alternate current machines where it is inconvenient to excite a machine by its own current.

Field magnets for dynamos and motors have been made in almost every conceivable shape. Electrically speaking the best form to use is one which has the most compact arrangement, presenting the shortest path for the flow of magnetism, the greatest cross section, and the fewest number of joints. Such a form would have the greatest permeability and would consequently be the most efficient. But the form which is most desirable electric-

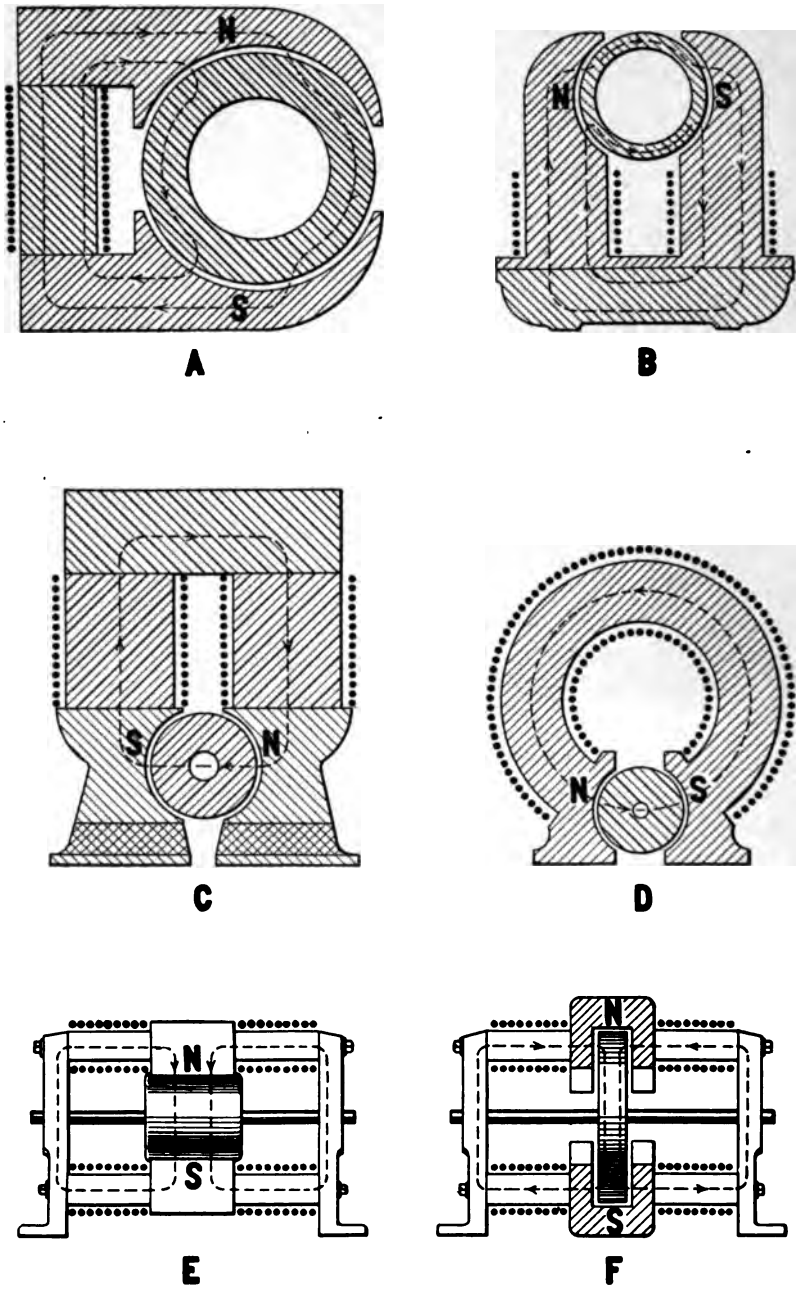


Fig. 15.

ally may often be very difficult and expensive to construct so that the forms which have become fixed in practice are usually the ones which have been found to give the best results at lowest cost.

Some of the more usual forms are shown in Figs. 15, 16 and 17. All types come under three principal heads; the single, the double, and the multiple magnetic circuit.

The horseshoe form is the type of the single circuit bipolar field magnet frame. It is placed upright, C Fig. 15, or inverted, B Fig. 15. The Edison machine is a type of the upright form, which has the disadvantage that it must be mounted on a zinc, brass or some other non-magnetic base, because if the latter were of cast iron, or any good magnetic conductor, the magnetism would be largely diverted by it instead of passing through the armature. The Thomson-Houston machines, now built by the General Electric Co., are of the inverted horseshoe type. The Jenney Electric Co. uses the horizontal type and the vertical form is employed by the Excelsior Electric Co. A modification of the horseshoe magnet type as generally used, is that employed by the Eddy Electric Co., D Fig. 15. In this machine there is no yoke and simply a half ring joins the pole pieces. This gives a very good magnetic circuit but is expensive to build. Another modification is the one magnet form, which has only a single coil wound on the portion of the frame corresponding to the yoke, as A Fig. 15, and this, like its prototype the double coil frame, is made in several positions.

The double magnetic circuit form is equivalent to two horseshoe magnets joined at the poles. The chief advantage of this type is in its greater mechanical strength. The coils are sometimes placed on the two upright sides which connect the top and bottom yokes, as shown by K. Fig 16 and P Fig. 17, the pole pieces being formed on the yokes. Again the pole pieces are elongated to make room for the coils and are placed either vertically or horizontally as shown by G and I. The double magnetic circuit type with internal poles (G Fig. 16) is called *ironclad* and is used in places where the machine might be exposed to accident. A modification of this type is used for street railway motors, the outside connecting pieces are thinned out and spread around the motor so as to completely cover it, affording perfect protection against injury from water or from mechanical means.

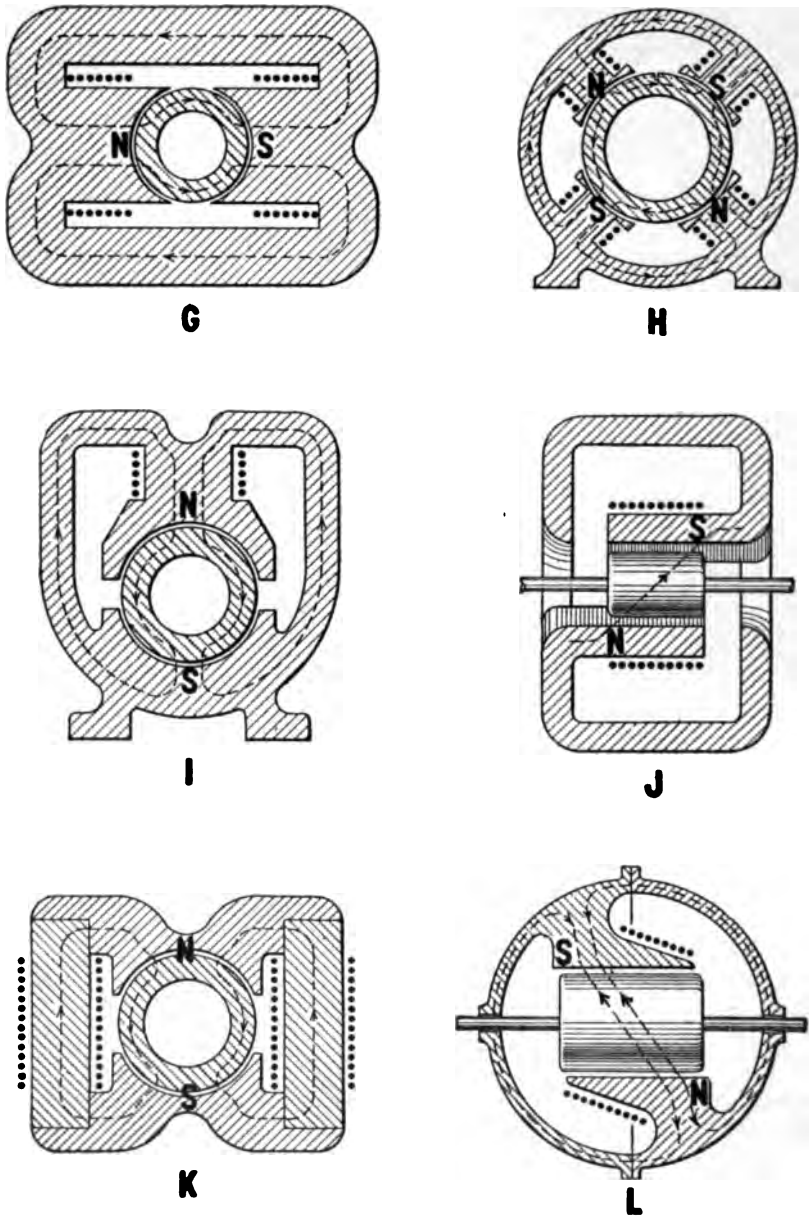


Fig. 16.

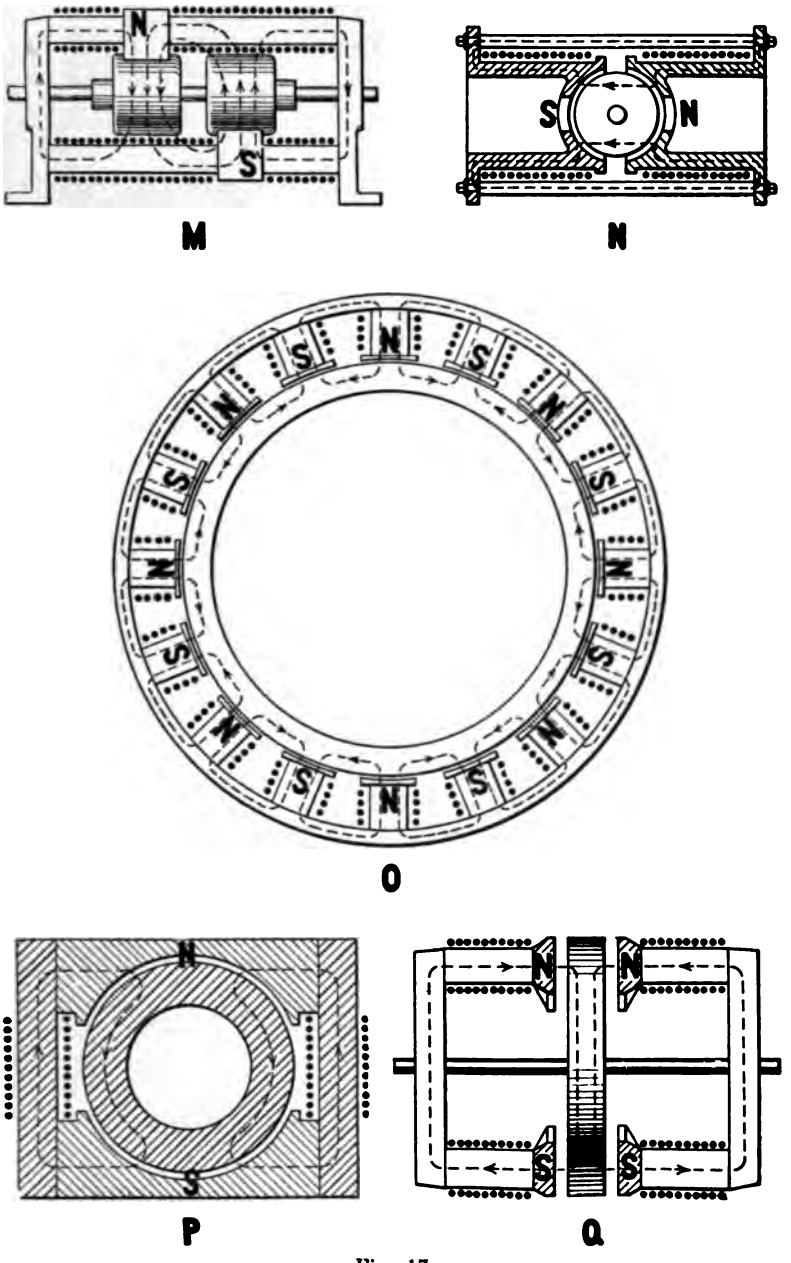


Fig. 17.

A curious modification is the Thomson-Houston "bird cage" arc light machine shown by N Fig. 17. It has tubular magnets and the pole pieces are formed to receive a spherical armature. The return circuit or yoke is made of wrought iron bars. The advantage claimed for this construction is that less wire is needed. Another ingenious form of the ironclad type is that used in the Lundell motor shown in section by L Fig. 16. There is but one coil which encloses the pole pieces, the whole being in turn completely incased by the remainder of the magnetic circuit.

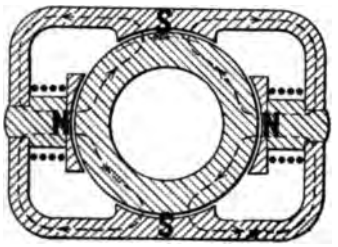


Fig. 18.

The double magnetic circuit type, modified by the formation of a pair of extra poles on the pieces which form the return circuit as in Fig. 18, gives rise to the four-pole type and hence to the multipolar multi-circuit type.

The multipolar field magnets are usually circular in form with inwardly projecting pole pieces. Siemens & Halske use a form having outwardly projecting pole pieces with the armature ring rotating outside the field as shown in Fig. 20. This gives a better magnetic circuit but introduces mechanical difficulties in securing armature supports. Sometimes the multipolar field is built with the coils on the yokes between poles instead of on them.

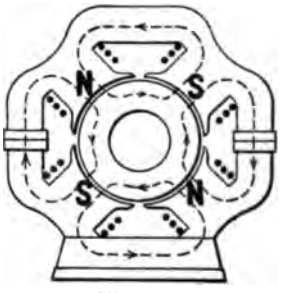


Fig. 19.

The circuit of the Ball dynamo is shown by M Fig. 17, and that of the Brush dynamo by Q. Fig. 19 and H Fig. 16 show magnetic circuits of typical small multipolar dynamos. The magnetic circuit of a large multipolar dynamo with inwardly projecting poles is shown by O, Fig. 17.

For large machines the multipolar type is most in use because it results in a saving of both copper and iron and gives a more symmetrical arrangement. Below 10 K. W. capacity the bipolar forms are to be preferred as they are simpler. The bipolar single circuit types are generally superior to the double circuit types

because they need less wire and are less subject to magnetic leakage.

DYNAMO CONSTRUCTION.

The Armature. The armature of a dynamo is that portion of the machine in which the electrical output is generated. The principle underlying every armature is the law of induction, that any conductor which cuts across a magnetic field has electromotive force generated in it which tends to set up a current. The various armatures of modern commercial machines are the mechanical means which experience has shown to be best adapted to carrying out the law of induction serviceably and efficiently under the various conditions and uses to which the machines are subjected.

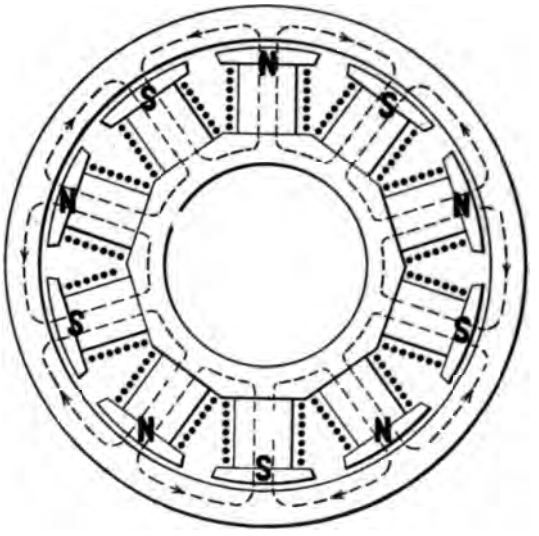


Fig. 20.

The two forms of armature in common use and from which nearly all others have been derived are the Gramme or *ring-wound* armature, and the *drum* or shuttle-wound armature. Fig. 21 shows a diagram of a simple ring armature with one coil, and Fig. 22 a diagram of a drum armature. In practice the number of coils on a single armature is of course large. In the Gramme type the iron core is a ring on which the coils are wound. In the drum type the core is a cylinder, the coils being wound on the surface and ends. Where slow speed is desired the ring armature is most generally used; the ventilation is better and a high insulation is more readily obtained.

There is also the pole armature, with its conductors wound upon iron cores projecting radially outwards; and the disk arma-

ture which has no core, the conductors forming a flat disk which rotates in a narrow gap between the pole pieces.

The Armature Core. The iron armature core not only serves as a support for the armature conductors but also serves as a medium of low reluctance through which the magnetic flux from pole to pole may readily pass.

If the core consisted of one solid piece of metal, it would, since it rotates in a varying magnetic field, have currents induced in it, as is the case in the conductors on its surface. The iron itself would form a closed circuit for these currents, which are known as Foucault or eddy currents. Their presence would not only be a waste of energy, but would also cause injurious heating. These currents are, however, largely reduced by laminating

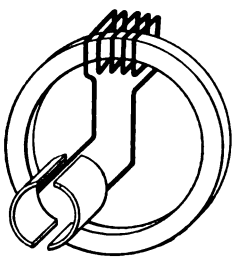


Fig. 21.

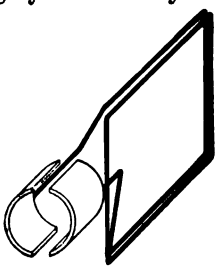


Fig. 22.

the core, that is, by building it up of thin insulated sheets of iron. These sheets or discs are perpendicular to the direction in which the induced currents would flow, and therefore break the otherwise closed circuit. The discs, being perpendicular to the direction of the induced currents are parallel with the lines of magnetic flux and therefore this lamination does not increase the resistance to the magnetic flux. The core of a drum armature is made up of a number of circular discs, and a ring core is made up of a number of similar rings. The discs may be insulated from each other by sheets of paper, a coating of varnish or by rust that is allowed to form on their surface.

The higher the permeability of the material of which the core is composed, the less will be the hysteresis loss and the greater may be the magnetic flux per unit of cross section; the core discs are therefore punched out of the softest sheet iron or soft steel, which in some cases is afterwards annealed.

It has largely become the practice to use **toothed** armature cores shown in Fig 23, the conductors being laid between the teeth and within the outside surface of the core. The air-gap between the core and pole pieces can then be reduced to a minimum, and the conductors are well protected from injury. The conductors are also securely held in place. Such cores are, however, more expensive to make and unless proper precautions are taken, the teeth are likely to set up eddy currents in the pole piece surfaces.

Armature cores are usually built up on an internal frame or skeleton which is in turn firmly keyed to the shaft. In drum armatures the core discs may be keyed directly to the shaft, or the shaft and hole through the discs may be made square or octagonal. The discs are sometimes held together by large nuts screwed directly on the shaft, or, as is usually the case, by bolts passing through the discs. In the latter case end-plates somewhat thicker than the discs are provided, and to reduce the presence of eddy currents which would occur if the plates were of iron, they are sometimes made of brass or other non-magnetic metal. These bolts and end-plates are always insulated from the core by tubes and washers of paper, fiber, or mica.

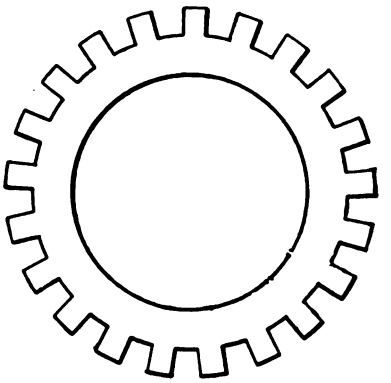


Fig. 23. Toothed Armature Core.

The core of ring and of large drum armatures, being in the form of a ring, must be supported on some form of spider. This consists of a hub or sleeve keyed to the shaft and is provided with projecting arms which support the core. A simple construction is shown in Fig. 24. Two spiders are used, the core being clamped between them. It will be noticed that the bolts do not pass through the core and therefore are not in the path of the magnetic lines.

Before the conductors are applied the core should have all sharp or rough edges removed. In order to secure good insulation from the conductors the cores are covered with a few layers of

insulating material; smooth cores have a continuous layer of insulation over their surfaces, whereas in toothed cores the insulation is applied only in the slots between the teeth.

Armatures of bipolar dynamos usually run at a speed of from 800 to 1,400 revolutions per minute; the armatures of direct connected machines and others which are of the multipolar type sometimes run as slow as 150 per minute, but their diameters may be so large that the peripheral speed is not far from that of a smaller machine. Under these conditions the centrifugal force acting on the conductors is quite appreciable.

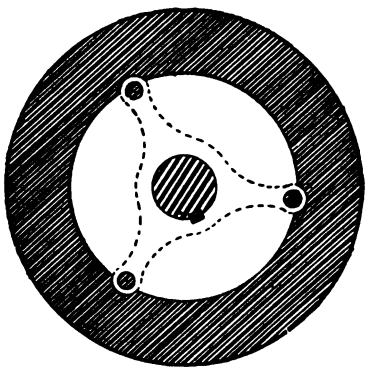


Fig. 24. Shaft and Spider Supporting Armature Core.

There is also another mechanical force to be provided for due to the magnetic pull exerted on the conductors by the field. It is against this pull that the steam engine driving the dynamo does work, and were they not strongly secured the conductors would be stripped from the armature. In order to prevent any motion of the conductors during the operation of an armature, hard brass wire is wrapped around the outside in bands; these are called **binding wires.**

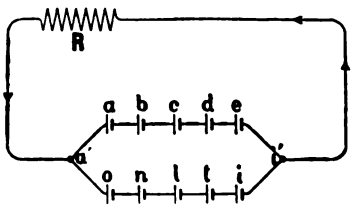


Fig 25.

On account of the high speed and small clearance in the air-gap, armatures are very carefully *balanced* to prevent injurious vibration. The usual method of doing this is to support the armature and its shaft on two horizontal, wedge-shaped metal rails called knife edges. The armature is then given a turn and it is noted whether there is any tendency to come to rest with any particular part of the armature downwards. If this is the case, small pieces of lead are inserted on the opposite side until the armature will come to rest in any position.

Armature Windings. The law of induction tells us that a

loop of wire carried through a field in such a manner as to vary continuously the number of lines of force that are included within its boundary will have an E. M. F generated in it. Two loops connected in series will double the effect, or twice the field strength will also double the effect. Dynamos are designed with this in view, and to produce the desired voltage the coils are made of a certain number of turns and the fields of a certain strength.

There are two general methods of winding armatures giving rise to the terms **closed coil** and **open coil.**

Closed Coil Armatures. The closed coil type of armature is used for constant potential machines, in incandescent lighting and power distribution, and in some cases for constant current machines. The coils are wound continuously around the ring or cylinder as the case may be, the end of one coil being joined to the beginning of the next, and this junction is connected with a segment of the commutator.

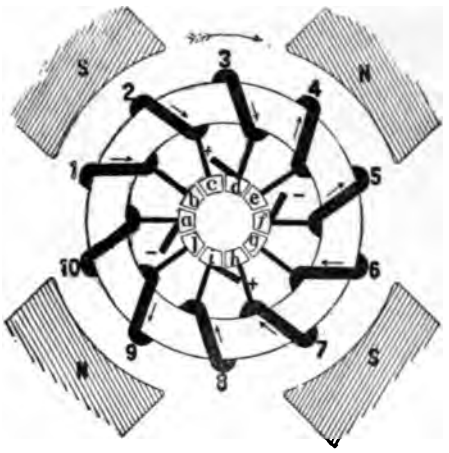


Fig. 26.

Each coil adds its quota to the electromotive force at the brushes, the amount depending at any moment on the position of the coil in the field. As the coils revolve the E. M. F. generated by some coils is increasing, while that generated by others is decreasing; but the sum total between the brushes remains the same, for the loss in effectiveness of one coil is balanced by the gain in another. The effect of the coils in a closed circuit winding is sometimes compared to a set of voltaic cells, one in each coil, as shown in Fig. 25. This would, however, be a more accurate illustration if the voltage of the cells were of varying strength according to their position in the chain. When two brushes are used there are two paths for the current from one brush to the other through the armature, and the resistance of the armature is then $\frac{1}{4}$ the resistance of the total amount of wire upon it, for the

total length of wire is halved and the halves are connected in parallel.

There have been many variations in winding, all based on the drum or ring winding, and resulting from the necessity of reducing the cost of manufacture and from the increase in the number of poles used in a single machine. The armatures of small machines are usually wound with copper wire, which in larger machines is replaced by copper bars, these bars being laminated above certain sizes to prevent the occurrence of eddy currents in their own mass.

The use of more than two poles greatly increases the variation which it is possible to make in the windings. Fig. 26 illustrates the winding and connections of a four-pole ring armature. As there are four neutral points it is necessary to use four brushes, two positive and two negative, the winding forming a closed circuit from brush to brush. To supply the external circuit the two positive brushes are connected giving one positive terminal, and the two negative brushes are connected giving one negative terminal. Thus the external current in passing through the machine subdivides at the two brushes and again subdivides in the armature, therefore only $\frac{1}{4}$ of the total current passes through each conductor. The internal resistance is $\frac{1}{16}$ of that of all the wire on the armature. Similarly more poles would cause the current to divide a greater number of times.

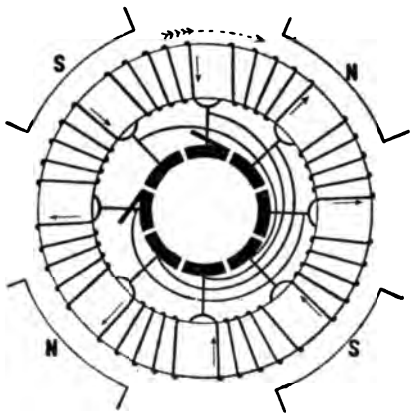


Fig. 27. Four-Pole Ring Winding.

It is not always necessary to have as many brushes as there are neutral points or poles, although this is usually the case. By the simple device of **cross-connecting,** a diagram of which is shown in Fig. 27, the number of brushes may be reduced to two. Each coil is cross-connected with others occupying a similar position under the corresponding pole. This cross-connection may be either in the armature itself or in the commutator.

A method by which armature windings and connections are clearly shown consists in laying the poles and winding out in a plane surface, or in showing the winding as it will appear when

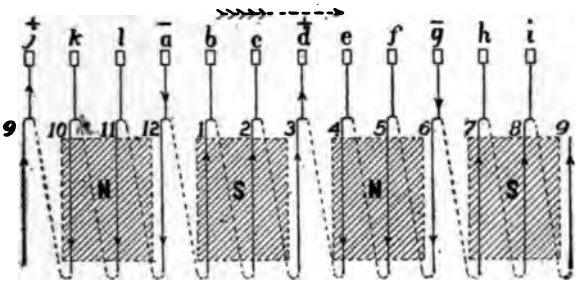


Fig. 28. Developed Ring Winding.

unfolded upon a plane surface. Such a development of the winding of a ring armature is shown in Fig. 28. Figs. 29 and 30 show two windings called the **lap** and the **wave winding** respectively. They are more like the drum winding than the ring, being entirely exterior to the core. A portion called an *element* is shown heavier than the remainder of the windings which are all similar to it.

A conductor on a revolving armature generates an E. M. F. under a north pole in the opposite direction to one under a south

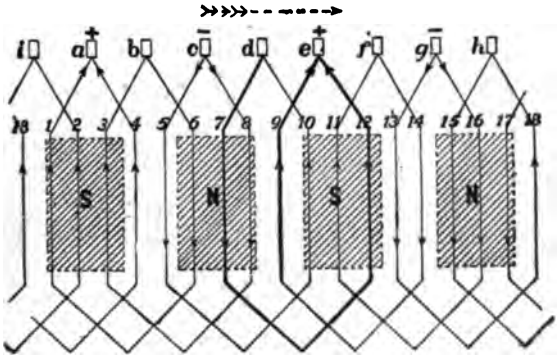


Fig. 29. Developed Lap Winding.

pole, so that it is possible to lay out a wire on the surface of an armature, carrying it across the ends from point to point, in such a way that it will be subjected to an inductive effect tending to

drive the current in the same direction throughout its length. The two ways of obtaining this result are illustrated in Figs. 29 and 30. The reason for calling them *lap* and *wave* windings is that one doubles back on itself every turn, while the other goes ahead in a continuous zig-zag, as will become apparent by following an element.

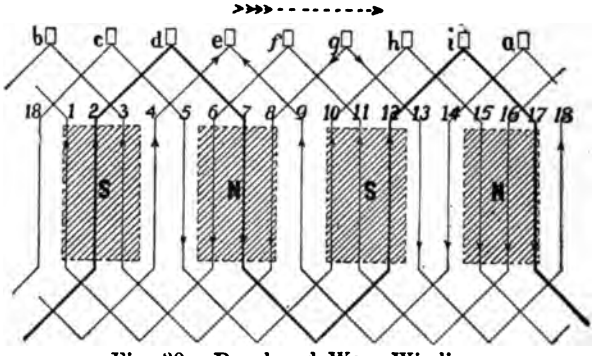


Fig. 30. Developed Wave Winding.

Open Coil Armatures. In the open coil type of armature, which is used chiefly for arc lighting or constant current machines, the various coils, which are few in number, are not interconnected; each winding performs its function independently of the others, and is cut into the circuit by the commutator at the time of greatest activity and is entirely disconnected from the circuit when it is idle.

The commutators of such machines are made up of few segments which are insulated from each other by air spaces. These machines generally spark considerably at the brushes on account of the actual break in the circuit of the separate armature coils.

Fig. 31 shows a diagram of a Brush arc machine which is ring-wound. There are four coils, the two coils *A* and *C* of one winding being in series and terminating in a two part commutator, while the others *B* and *D*, also in series, terminate in another two part commutator. The commutators are placed side by side and the segments are made long enough to overlap so that sometimes the brushes are connected to one pair of terminals, sometimes to the other, and sometimes to both at once. When the brushes *E E* touch both sets of terminals at once thus bringing the two wind-

ings in parallel, a current would be set up in one winding by the other owing to the difference in activity of the two, were it not for the high self-induction of the coils. The contact between the brushes and a pair of terminals breaks just when the coils connected have reached the point of least activity. The completed

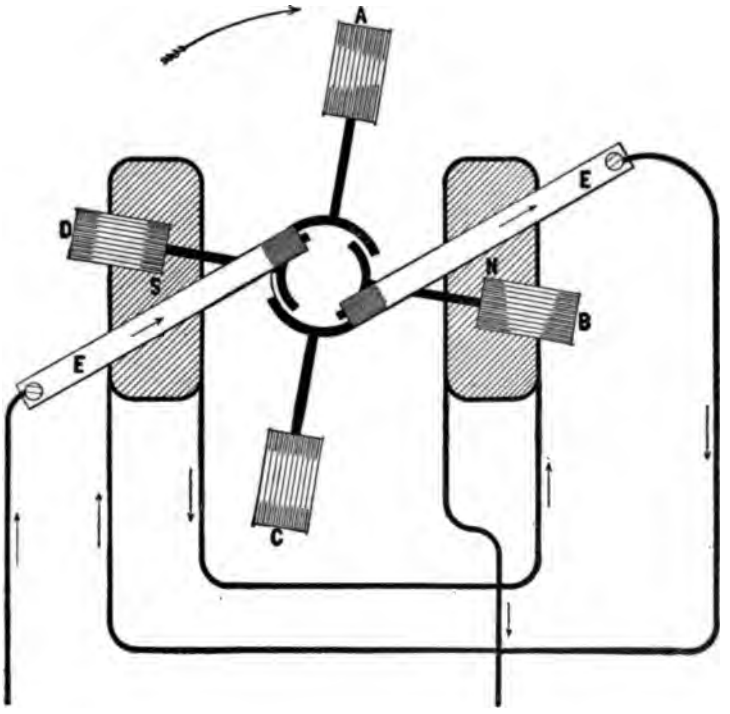


Fig. 31. Diagram of Brush Arc Dynamo.

dynamo has another set of coils between those shown, on the same ring, and another commutator and pair of brushes beside the first set. One brush of the first set is connected to the outside circuit, the other is connected to one of the brushes of the second set while the remaining brush is connected to the other terminal of the outside circuit through the field coils. In this way the two sets of windings are brought in series with each other and owing to their relative positions, one is at a maximum activity when the other is at a minimum, one increases as the other decreases, and *vice versa*, so that the sum total of the action tends to keep the current from fluctuating.

Commutators. It has been shown how current generated in a coil revolving in a magnetic field is necessarily alternating, being generated in one direction through the coil when the coil is rising through the field and in the opposite direction when it is descending. The first machines built were alternating current machines, but as the alternating current could then only be used for a few purposes the invention of the commutator soon followed. The simplest form of dynamo is a single coil revolving in a field, the terminals of the coil ending in two pieces of metal which form the halves of a circle, and with which the brushes are in contact. As the coil rotates, first one terminal and then the other comes

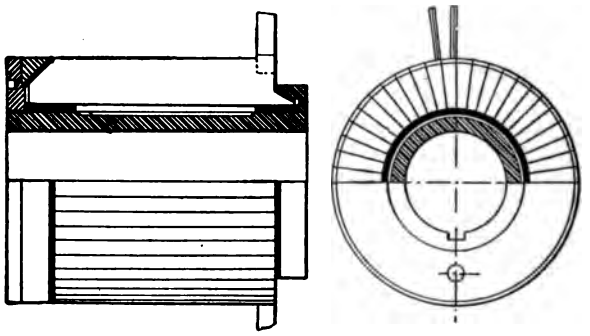
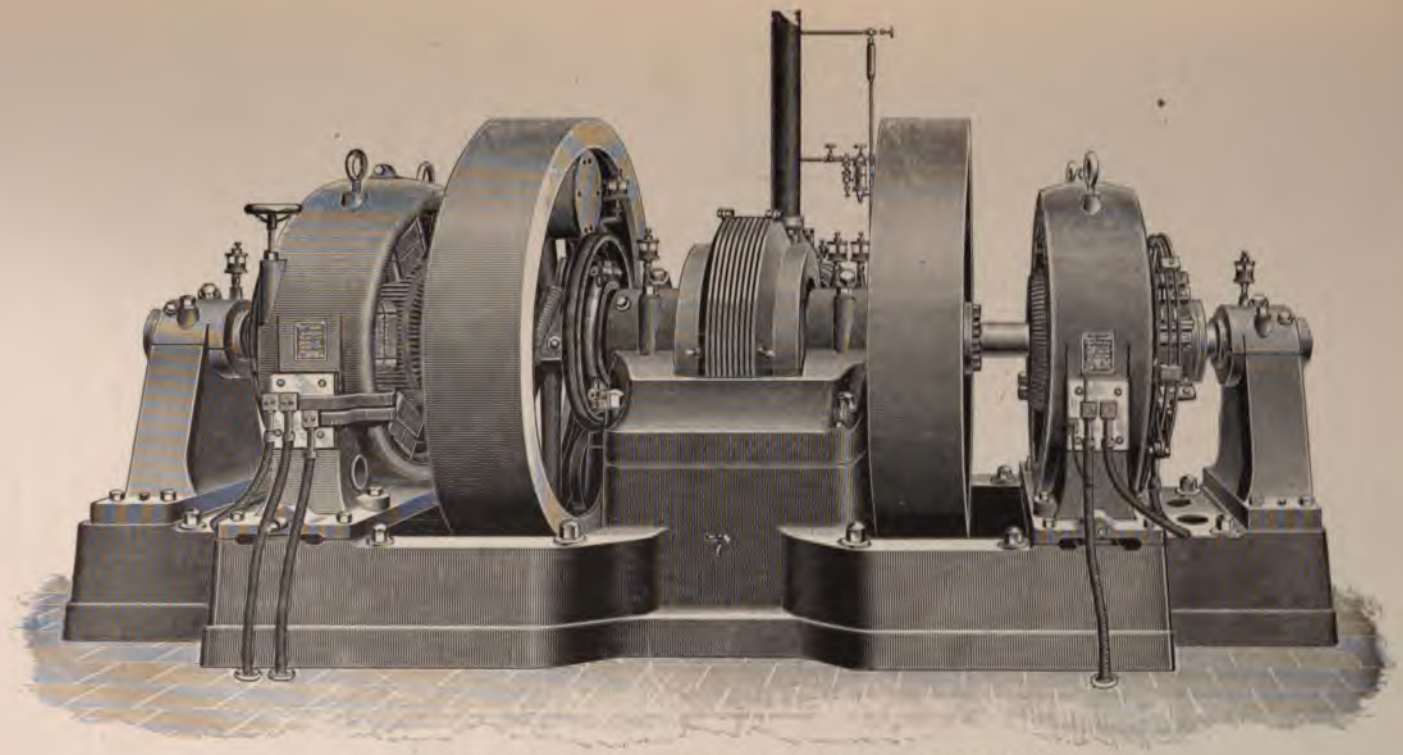


Fig. 32. Commutator.

under a brush. If the brushes are put in the right place the terminals will always have the same polarity when they make contact with the brushes so that a continuous current can be drawn from them. The current is continuous however, only as regards direction for the strength of the current is varying.

As the coil moves into the denser part of the field the current increases, and as the coil moves out the current decreases. If we had two coils at right angles to each other, moving through the field in the same time, the pulsation would only be half as great as with one. We can therefore make the pulsation as small as we like by increasing the number of coils and hence the number of commutator segments. The fluctuations become perceptible in a two pole machine when less than 30 coils are used and the commutator bars seldom exceed 100 for this type of machine on account of increased expense. In larger machines the



ENGINE DIRECT-CONNECTED WITH TWO WESTINGHOUSE GENERATORS.
Ames Iron Works.

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ASTOR, LENOX
TILDEN FOUNDATIONS

total number of commutator segments increases with the number of pairs of poles.

The commutator must be well designed mechanically as well as electrically. Each segment must be carefully insulated from adjacent ones and from the shaft upon which it is built up. The insulation between the segments consists of sheets of mica which have been selected for firmness, freedom from cracks, and uniformity in thickness. The segments taper toward the center so that they will build up into a cylinder. The whole is firmly clamped together by insulating rings held in place by metal rings and lock nuts. Figs. 32 and 33 show two different methods of securing the

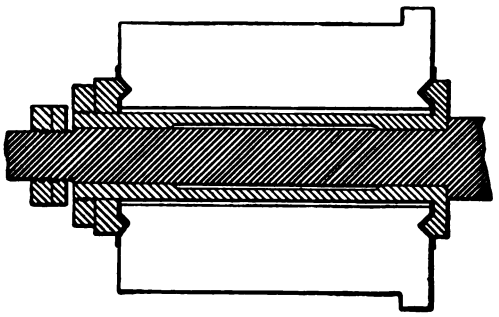

Fig. 33. Commutator.

assembled commutator bars. The best material for the commutator bars is hard copper or silicon bronze which should be as nearly pure as possible and uniform in its structure. The commutator is designed larger than necessary so as to allow for the continual wearing away of its surface; and also to allow it to be turned down from time to time when the surface becomes rough as the result of uneven wear or accident.

Brushes. The cross section of the brush must always be large enough to carry the maximum current which it is likely to be called upon to furnish, with a liberal factor of safety. The thickness at the contact with the commutator should not be less than one and a half times the insulation between the bars and is usually greater. The material must be softer than that of the commutator so as to wear the brush rather than the commutator.

There is a large number of different forms of brushes, each having its special advantages and disadvantages. In the Brush

arc dynamo the brush consists of a simple strip of sheet copper having slits in it to insure good contact, and is set almost tangent to the commutator.

The wire brush has been much used and is still employed; it consists of a bundle of fine copper wires all soldered together at the end furthest from the commutator, and being inclined to its surface, the brush has the contact end beveled to fit the commutator in order that the ends of all the wires may make contact.

Copper gauze brushes consist of sheets of fine copper gauze folded or rolled up and pressed into rectangular form. These brushes owing to their soft spongy nature secure excellent contact with the commutator.

The carbon brush is now used more than any other. It is usually applied radially giving the advantage that if the machine is run backwards, through accident or intention, there is no danger of ruining the brush by causing it to trip on the edge of some commutator bar that might be slightly out of place. It also wears a better surface on the commutator and the amount of wear is much reduced. The collection of carbon dust is far less objectionable about a commutator than that of copper dust being less likely to cause a short circuit. The main advantage of the carbon brush is the reduction of sparking. As carbon has a high specific resistance it tends to keep the current down when the commutator bars are short circuited by coming under the brush, and there is therefore little or no sparking when a bar breaks contact with the brush. This advantage becomes less marked in machines having many segments in the commutator and very low difference of potential between them, for in such machines there would be little sparking even with copper brushes having high conductivity.

Brush-Holders. The brush must be held rigidly in position by a mechanism called the **brush-holder** which is capable of being revolved part way around the shaft so as to shift the point of contact between the brush and the commutator. The holder is usually mounted on a collar which in turn is mounted on a hub formed by a projection from the journal box. An insulated handle is provided by which to shift the brushes to the desired position, and it is often made to screw into the collar in such a way that the brush-holder can be locked in any position. In very

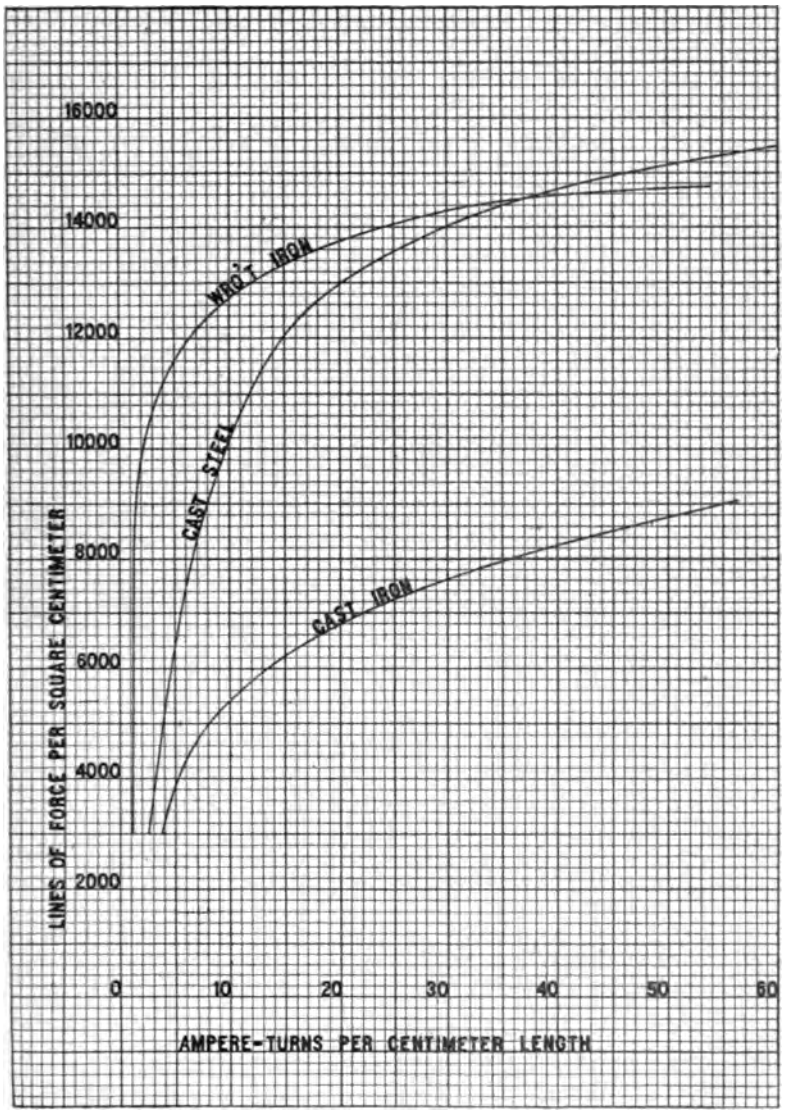

Fig. 34. Curves of Magnetic Induction.

large multipolar machines where there are as many brushes as poles, a substantial ring is formed separate from the machine. This ring is supported from the field casting by arms, and is shifted by the aid of a hand wheel and worm meshing with teeth on the ring.

Except in very small machines brushes are subdivided into two or more parts pivoted on the same shaft of the brush-holder. By this means of construction one brush at a time may be lifted and examined without breaking the circuit or interfering with the operation of the machine. The brush-holders are generally provided with adjustable springs which give the brushes a proper pressure on the commutator. If much of the current is allowed to pass through the springs, they are heated and soon lose their temper, and they cannot then exert sufficient pressure on the brush. The springs are therefore insulated, or arranged so that only a very small part of the current passes through them.

Field Magnets. In the construction of the field magnets the principal materials used are cast iron, cast steel, and wrought iron. Usually a combination of two of these is used. In Fig. 34 are shown curves of magnetic induction for cast iron, wrought iron and cast steel.

Cast iron has the lowest permeability of the three and hence for a certain magnetic flux must necessarily have a larger cross section. It is customary to allow a density of about 45,000 lines per square inch for cast iron. This material is used, on account of its cheapness, for yokes, polepieces, bases, or in general where extra weight or size is not objectionable. This extra weight is often an advantage since it gives greater firmness and stability.

Wrought iron is generally considered to have the highest permeability of any material and a density of about 90,000 lines per square inch is usually allowed. Owing to its high permeability, wrought iron is used where a small cross section is desirable, and this is especially the case in field cores. To wind a certain number of turns upon a wrought-iron core will require a considerable less length of wire than if a core of some other material large enough to carry the same magnetic flux were used. If a cast-iron core were used the length of wire would be about 1.5 times that needed for a wrought-iron core for a given number of turns.

The improved and cheaper processes of casting soft steel having a low percentage of carbon, has led to its adoption for field magnets in many dynamos. Cast steel has a very high permeability and some varieties have a higher permeability than that of wrought iron; it is customary however to allow a density of about 80,000 or 85,000 lines per square inch. Cast steel is always used for field magnets where lightness and small size are desirable.

Field Coils. For convenience in construction and repair of field coils they are usually wound on a separate form and then placed in position on the cores. The cylindrical form upon which they are wound often consists of tubes of brass or tin, having flanged ends. The coil should be insulated from this tube by a few layers of thick paper or fibre. The finished winding should be perfectly symmetrical or as nearly so as possible. The leads from the coil should be carefully protected and insulated; this is especially the case with the inner terminal, which is usually carried out through a hole in one end of the tube or spool.

As the conductors of series coils often must be of large size, they are difficult to wind, and therefore usually consist of several smaller wires connected in parallel, or of ribbons or strips of sheet copper. In compound-wound machines the series and shunt windings may be separate or on the same spool. In the latter case the shunt coil and series coils are wound in separate compartments of the spool. When the coils are separate there is the advantage of greater ease in repair and also greater radiating surface.

SPARKING.

It sometimes happens that heavy sparking takes place at the brushes of a dynamo and if this is not prevented it soon burns and roughens the surface of the commutator and the brush so badly that the dynamo is thrown out of service. Sparking may result from either mechanical or electrical faults. If one bar of the commutator is higher or lower than the rest there will be a spark every time it passes under the brush, or if the lead from an armature coil to one of the commutator bars should become disconnected, or if there should be a break in some other part of the

coil, there will be flashing when the bar passes under a brush. If the sparking is continuous and not due to mechanical causes the brushes should be rocked one way or the other until a position is found where the machine runs sparklessly, or nearly so.

When a dynamo is in operation the current passes from the positive brushes through the external circuit to the negative brushes, and then sub-divides and passes through the armature to the positive brushes. To understand the production of sparking due to an incorrect position of the brushes it is necessary to consider the commutation at one brush only.

Referring to Fig. 35, it is evident that the current passes through coils 2 and 3 to segment *d* in one direction and through coils 5 and 4 to segment *d* in the opposite direction. From segment *d* the current passes to the positive brush and to the external circuit. Further movement of the armature in the direction of rotation will bring both segments *c* and *d* under the positive brush at the same time and coil 3 will then be short circuited. That is, these two segments, the brush and coil 3 will form a complete circuit of very low resistance, and the current may pass from coil 2 directly to segment *c* and the brush, and from coil 4 directly to segment *d* and the brush. As the armature continues to rotate, coil 3 will come under the north pole and segment *c* under the positive brush. The current must then pass from coil 4 through coil 3 to segment *c* and the brush. In passing the brush coil 3 is therefore at first short circuited and afterwards is traversed by a current in the reverse direction to that originally considered. Each coil successively passes through the same positions. Now, suppose the position of the positive brush is such that when coil 3 is short circuited it is cutting no lines of force and therefore generating no E. M. F. Then there will be no current and as the coil passes to the right it will be perfectly idle, and when segment *d* leaves the brush the large current from coil 4 should pass through coil 3 to get to segment *c* and the brush. On account of

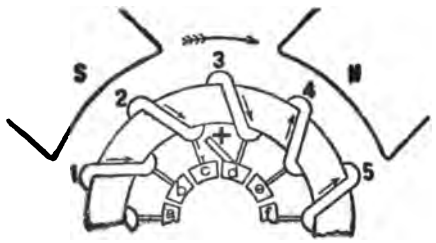

Fig. 35

the large self-induction of the coils, however, the current cannot immediately rise to its full value in coil 3 and hence will prefer to jump from segment *d* to *c*, causing sparking. Now consider the result when the brush is shifted to the left or backwards, so that when the coil is short circuited it is still cutting lines of force. The generation of a slight E. M. F. will cause a large current to flow on account of the very low resistance of the coil, and the direction of this current will be opposite to that which the coil must next convey. For such a position of the brush excessive sparking will result.

Now consider the brush to be moved forward or to the right, so that while the coil is short circuited it is passing into the field at the right or under the north pole. The E. M. F. generated by coil 3 will then cause a current to flow which will be in the same direction as that in coil 4, and when segment *d* passes from under the brush the current in 3 already has a certain value. The correct forward position of the brush is such that coil 3 generates just sufficient E. M. F. to produce a current equal to that which passes in coil 4. No sparking will occur under these conditions, as the effect of self-induction has been counteracted and the current from coil 4 will readily pass to 3. If the brush is too far forward, too large a current will be generated, and cause sparking. The brush must be set forward a greater amount for large armature currents, since the short-circuited coil must generate a higher E. M. F. to produce the large current. The distortion of the field by the armature also necessitates the shifting of the brushes forward.

INSTALLATION AND OPERATION.

A good foundation is the first requisite in a dynamo installation. With belted machines the high speed may give trouble if the foundation is insecure. With direct driven machines the engine and dynamo should be mounted on the same bed plate if the size permits. In selecting a position for the dynamo, freedom from dampness and dust should be secured and also good ventilation. A belted dynamo should be far enough away from its driving pulley to allow the belt to have good contact. A modern direct connected unit of 15 K. W. capacity is shown in Fig. 86.

Most machines of modern design are furnished with self-aligning and self-oiling bearings. If there are a number of machines in one installation each of which is fitted with oil cups, it may be advisable to have a system of oil pipes arranged to dis-

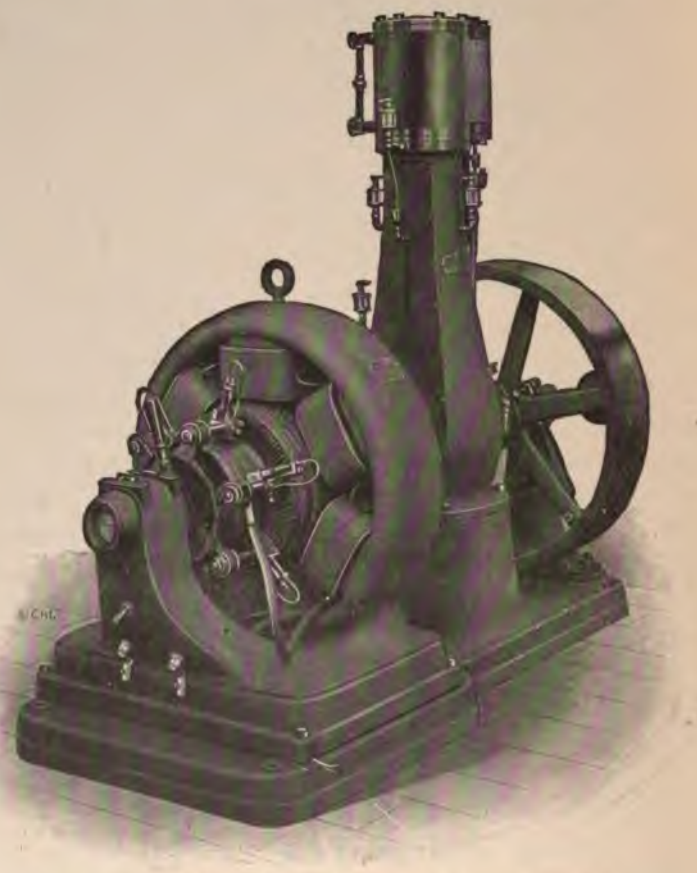

Fig. 36. Fort Wayne Direct-Connected Generating Set.

charge oil through a stop cock into the oil cups. All oil cans should be of non-magnetic material, to prevent accidents which might arise from the attraction that would be exercised on an iron can when placed near some parts of the dynamo.

All electrical machinery should he kept scrupulously clean.

Brushes should at all times be kept in good contact with the commutator, with their faces properly bevelled, and if they are of metal, the armature should never be allowed to run backwards. The commutator must be kept smooth and polished, as any roughness will cause sparking and a burning of the surface. If each brush-holder supports two or more brushes as is generally the case, they should be staggered enough to prevent uneven wearing of the commutator. The commutator is the most delicate part of a dynamo and consequently requires special care. Commutators should be kept free from oil, as it will carbonize and cause flashing and may even partially short circuit the bars. Where carbon brushes are used the carbon dust should be wiped off from time to time. Some lubricant is generally necessary for the commutator, and it may be applied by holding against it a coarse cloth folded smoothly and containing the lubricant. Vaseline is generally used.

The position of the brushes should be such that the machine runs sparklessly and when a change of load causes sparking the brushes should be shifted at once to the right position, as the commutator will become so badly roughened if allowed to run long in this condition, that it will have to be turned down with a cutting tool. The term *sparkless* means that there are no sparks present sufficiently large to burn the metal. When a machine is running it is possible by looking tangentially to the commutator at the brush to see a line of these blue sparks under the brush.

Dynamos as a rule are not liable to many mishaps if they are properly built and if they receive proper care, but it is often difficult to locate certain faults. A new machine will sometimes refuse to generate when first started; this is often due to entire absence of residual magnetism, making it impossible for the machine to build up. This may be remedied by exciting the field from an outside source, either another machine or a battery. It is however more likely to be due to some bad connection, such as would be produced by getting varnish under a terminal washer or by a loose wire. Sometimes the terminals of the field coils are reversed so that they oppose each other, or perhaps the brushes do not make sufficiently good contact. A shunt machine will not build up if its terminals are short circuited.

Burn-outs in the armature are sometimes produced by exces-

sive heating resulting from overload. A short
often throw the belt or stop the engine so quic
not time for the armature conductors to me
loads not great enough to throw the belt may
until two conductors lying side by side and dif
other in potential, come into contact. Vibra
balanced armature or to an insecure foundation
same trouble by causing abrasion of the insula
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core. Dirt between two adjacent commutato
collection of copper and carbon dust, may sho
having terminals in these bars sufficiently to
Sometimes the connecting pieces between the
the commutator segments become broken

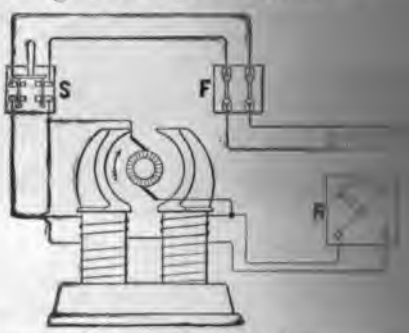


Fig. 37. Diagram of Connections of a Compou

armature electrically, and causes sparking at the
bar.

The connection between a dynamo and
should always be made through a double-pol
both terminals from the circuit. A diagram o
nections and wiring of a compound-wound
Fig. 37. The leads from the external circui
to the fuses *F* in order to protect the dyn
dangerous currents. If a current greater tha
dynamo passes through these fuses they mel
circuit. From the fuses leads connect wi
and from this to the brushes through th
rheostat *R* is connected in series sh

pose of regulating the field strength and hence the voltage of the machine. By moving the arm of the rheostat, more or less resistance is inserted or cut out from the circuit and therefore the current in the field coils is varied.

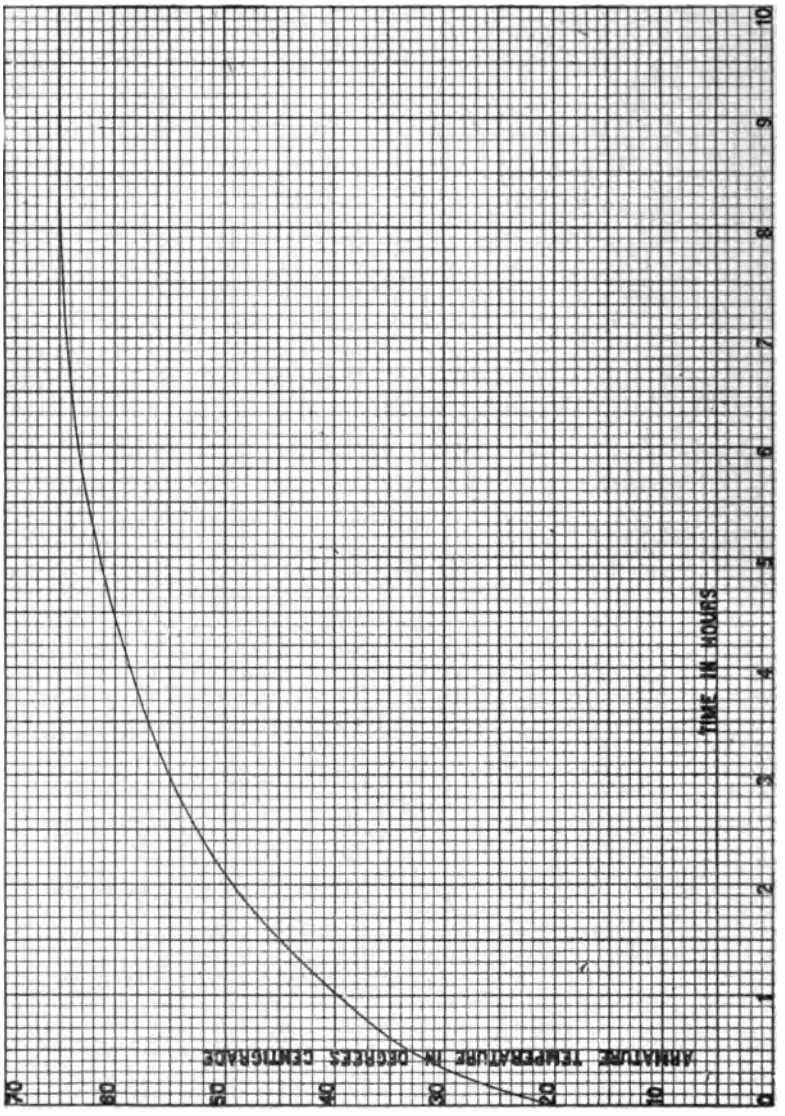
In most stations supplying electrical energy it is not desirable to have a single machine capable of taking the whole load of the station, for at low loads the efficiency would be small. It is therefore desirable to have several smaller machines, so that as the load of the station increases they can be successively added, and so always operated at full load when they are most efficient. The several machines are then connected in parallel between the bus bars from which the external circuits lead.

With shunt machines no trouble is experienced when several are running in parallel. Care must be taken before connecting a new machine to the circuit that it is built up to the same voltage as that carried on the bus bars, for if it is lower the higher voltage will send a current to the machine of lower voltage and drive it as a motor.

With series or compound machines the case is somewhat different. A conductor called an equalizer must connect together all the brushes from which the series coils start. Otherwise any tendency in one machine to raise its potential above that of the others would cause increased potential at the brushes and hence an increased current through the shunt coils, which would still further raise the potential; and if the potential became high enough it would reverse all the other machines on the circuit. This action is entirely obviated by the use of the equalizer, for if the potential of any machine should tend to rise it would drive some of its current across the equalizer connection and through the series coils of the other machines thus raising their potential with its own. Machines differing widely in size can be run together in this way if all are wound for the same potential.

TESTING.

When machinery has been installed it is customary to subject it to certain tests to determine whether or not it fulfills all the requirements. No test can be applied to determine the life of the machine. The life depends upon the general design, material of which it is made,


ARMATURE TEMPERATURE IN DEGREES CENTIGRADE
70
60
50
40
30
20
10
0
TIME IN HOURS
1
2
3
4
5
6
7
8
9
10

care used in its construction, and the care it receives during its operation. Only previous experience with similar machinery is of any value as a guide in this respect.

With proper care and good materials the only defect that is likely to shorten the life of the dynamo is overheating. It is customary to specify that a machine shall be so designed that it may run continuously at full load with a rise of temperature in the armature conductors not exceeding 40° C. above the surrounding air. The commutator may be allowed to reach a slightly higher temperature, say 5° or 10° greater. The effect of overheating is to gradually char and weaken the insulation. This test is easily made after the dynamo has been in operation for a few hours at full load by placing thermometers in the armature windings at the back and front where the windings are accessible and allowing them to remain there about ten minutes covered with waste. In general the above requirement is well within the limits of safety. Fig. 38 is a curve of the rise in temperature of an armature when in operation.

In electric light supply it is very essential that the voltage at the lamps should remain at its proper value. If it is too high the lamps will be unpleasantly bright and their life will be much shortened; if too low the lamps will burn too dimly. If short, quick variations occur, even though very small the effect will be noticed in the lamps as flickering. Hence, it is desirable that the engine driving the dynamo should regulate its speed with extreme closeness. Flickering is avoided by the use of a sufficiently heavy fly-wheel, whose proportion will depend on the speed, point of cut off, and length of stroke. It is usual to specify that the variation in speed of the combination of engine and dynamo from no load to full load shall not exceed 3%, and the change in speed during each stroke of the engine must not exceed one per cent so that flickering in the lamps will not be noticeable.

A characteristic curve should always be taken as well as a speed curve, and if the machine is over-compounded to keep the voltage constant at some particular point on the feeder system, a curve for this point should be constructed by subtracting the volts lost in the mains from the external characteristic curve.

Multipolar machines can be built to run sparklessly under sud-

den variations in load as great as from no load to full load, and tests should be made by repeatedly throwing on and off certain proportions of the load, and noting the amount of sparking. It is needless to say that under a steady load the machine should run sparklessly. In many machines the position of the brushes depends somewhat on the load and requires shifting with the load.

If an insulation resistance test is made, it should be done when the machine is hot, and a source of electrical energy at considerably higher voltage than that for which the machine is built should be used, generally from 5 to 10 times as great. One pole is applied to the iron core and the other to the armature winding; if the insulation resists this test, no puncture being formed, it is without doubt free from any defect.

The efficiency of any machine is expressed by the ratio of the energy that it gives out, or output, to that which is supplied to the machine or input. This ratio multiplied by 100 gives the percentage efficiency. If the efficiency of a dynamo is 85 %, then 85 % of the mechanical energy supplied to the machine at the pulley, will reappear as available electrical energy at the terminals, while 15% is lost. The losses are both mechanical and electrical. The mechanical losses are simply the result of friction in the bearings and brushes besides air friction due to the revolving armature. The electrical losses are due to the resistance of the armature and fields, being equal to the square of the current multiplied by the resistance. There are also additional electrical losses from eddy currents and hysteresis.

To determine the total or commercial efficiency there are several methods, mechanical and electrical, in use. If the machine is run from a belt and shaft a dynamometer can be used. There are many different forms of these machines in existence, the principle underlying them being to pass the pull of the driving power through some form of spring which is bent proportionately, the amount of the force exerted being indicated by a pointer on a scale which can be graduated to read in pounds pull. Knowing the pull applied at the circumference of the dynamo pulley, its radius, and the number of revolutions per minute, the horse-power supplied to the dynamo is found by the formula

$$\text{H. P.} = \frac{2\pi n P r}{33{,}000},$$

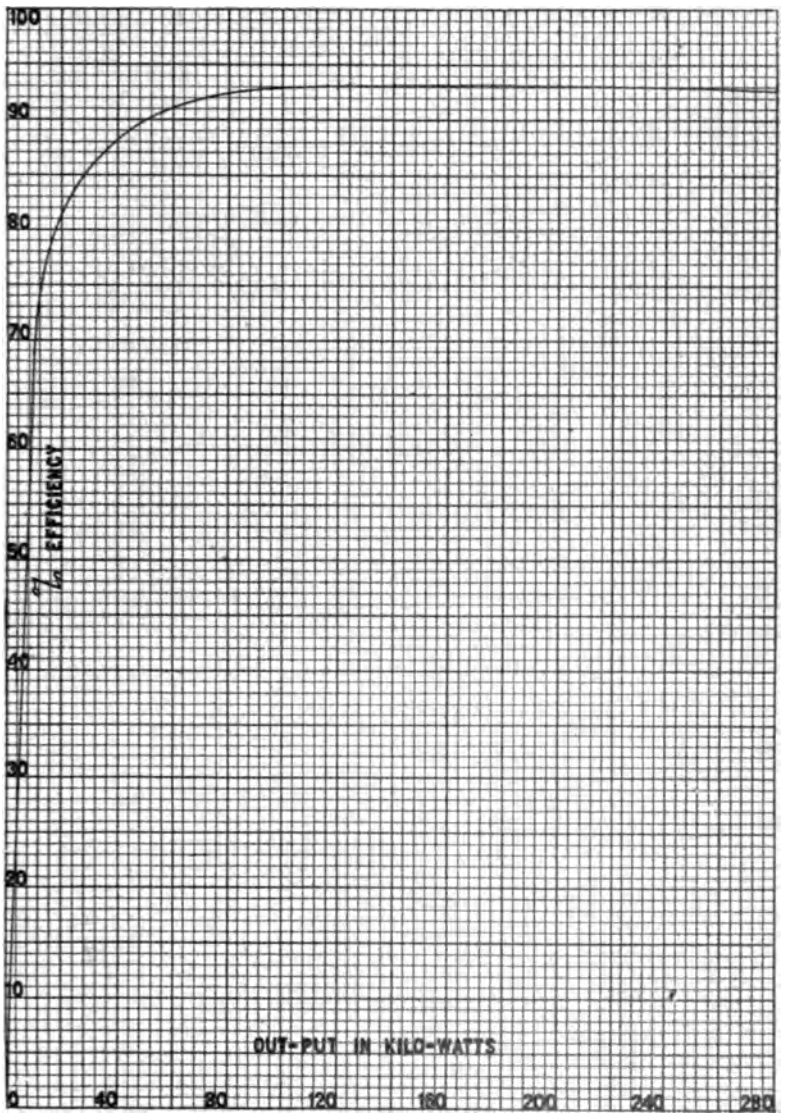


Fig. 39. Efficiency Curve of 200 K. W. Dynamo.

where n is the number of revolutions per minute, F the pull in pounds at the circumference, and r the radius of the pulley in feet.

Knowing the horse-power supplied and the horse-power taken out as given by the product of the current times the terminal voltage divided by 746, the commercial efficiency of the machine in per cent is obtained by multiplying the ratio of the latter result to the former by 100.

The efficiency is of course very much lower at light loads than at full load because friction is practically a constant quantity for a machine running at constant speed, so that the energy consumed by it bears a much greater proportion to the input at low loads than at high.

An efficiency curve of a Crocker-Wheeler direct connected multipolar 200 K. W. machine for lighting purposes is shown in Fig. 39.

It is not always possible to use a dynamometer, as for instance in the case of a direct connected machine. Under these circumstances the best method is to drive the dynamo as a motor with no load, and note the current required to just keep the machine moving at normal speed. This current multiplied by the voltage at the terminals gives the wasted power. The losses at full load are greater since the current is greater, and the $I^2 R$ losses then have a larger value.

With direct current machinery it is sometimes convenient to take indicator cards on the steam engine from which the steam power developed can be calculated, and at the same time to note the electrical output at the switchboard, the ratio of the two giving the efficiency of the combination. This procedure is only permissible when the load is quite steady; any attempt to do this on a railway generator in service is out of the question, because owing to the fly wheel sudden changes of load are not felt simultaneously in the engine and dynamo. A momentary drop of 30% or 40% in the electrical load would probably not reduce the indicated horse-power in the engine at all for a short space of time; the power thus liberated would go into speeding up the fly wheel.

The best method for obtaining a steady load on a dynamo is to pass the current through a water resistance or rheostat consist-

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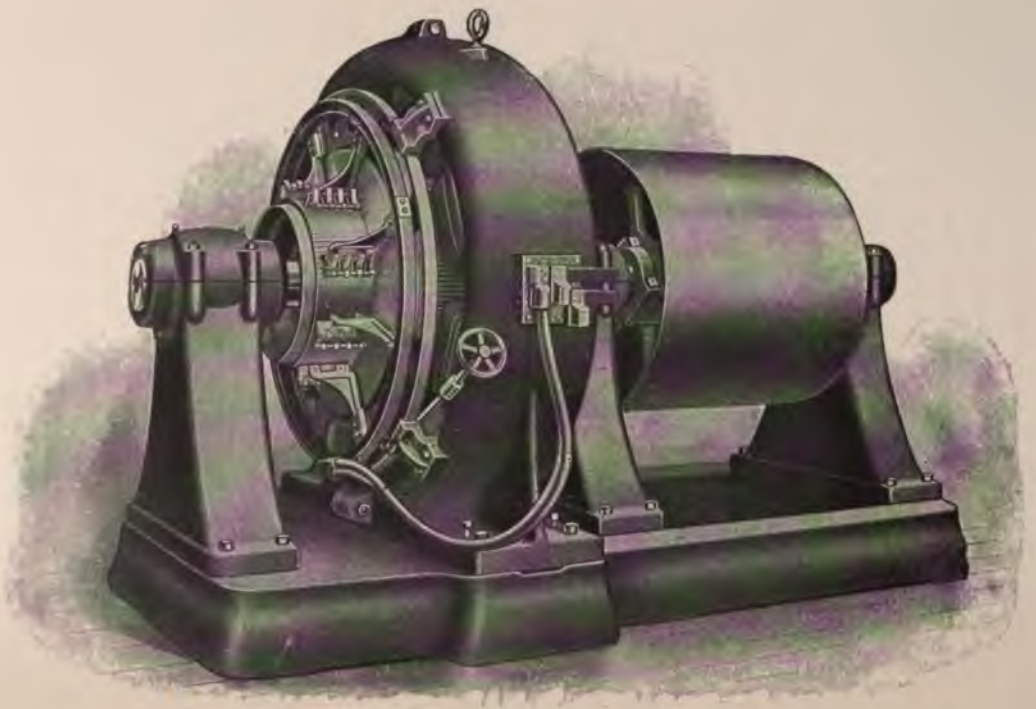

350 K.W. 350 R.P.M. THREE-BEARING BELTED GENERATOR.

Triumph Electric Company.

ing of a wooden tank filled with water in which hang two iron plates. The terminals of the dynamo are connected with the iron plates, and the resistance and consequently the load is varied as desired by bringing the plates closer together or moving them farther apart. An arrangement which answers the purpose very well can be made from an ordinary barrel with 4 positive plates and 4 negative plates 12″ x 24″ and $\frac{1}{16}$″ thick, held apart by narrow boards 1″ thick placed between them. These boards should be made longer than the plates, so that they can be nailed together above and below. Ordinary furnace grates will also do very well.

Regulation can be secured by suspending the plates by some means above the barrel. They may then be lowered into the barrel to any desired depth. A cold-water supply should be furnished at the bottom of the barrel and an overflow pipe at the top. In this way the water can be carried away as fast as it is heated by the passage of the current. This apparatus will take care of 100 amperes at 550 volts. By adding a handful of salt to the water its capacity can be increased to 300 and even 400 amperes, but at such high values the ebullition is likely to become so great as to be unmanageable.

DYNAMO FORMULAS.

The complete analysis of the dynamo would be out of place here, but several important formulas will be developed to indicate the method.

For the *shunt dynamo* the analysis is as follows:

Let I' = total current in armature;
I_{sh} = current flowing in shunt coils,
I = useful current flowing in outside circuit;
E' = total E. M. F. generated in armature;
E = potential of dynamo, both for shunt coil and outside circuit;
r_a = resistance of armature;
r_{sh} = resistance of shunt field coils;
R = resistance of outside or useful circuit;
π_e = electrical efficiency.

These various quantities can be expressed in terms of each other in a number of different ways. This is of value in studying and understanding the characteristics of the shunt dynamo, and in finding the values of unknown terms when others are known. It is obvious by looking at diagram of Fig. 5 that the total current is the sum of the outside current and shunt current, or

$$I' = I + I_{sh} \text{ or } I' = I + \frac{E}{r_{sh}}$$

This latter equation shows what amount of the armature current is lost in the shunt field. Also the total current in the armature is equal to the total E. M. F. divided by the total resistance,

$$I' = \frac{E'}{r_a + \frac{R \times r_{sh}}{R + r_{sh}}}$$

because the joint resistance of the shunt and outside circuits (see section on the *Electric Current*) is equal to the product of the two divided by the sum of the two.

The relation can be expressed in still another way, since

$\frac{E}{R} = I$ and $\frac{I}{I_{sh}} = \frac{r_{sh}}{R}$ from which $I' = \frac{E}{R}\left\{1 + \frac{R}{r_{sh}}\right\}$

E, R, and r_{sh} are often known quantities from which I' and E' may be found by the aid of these relations. The value of the useful current in the outside circuit is

$$I = \frac{E}{R}$$

and the value of the current in the shunt circuit is

$$I_{sh} = \frac{E}{r_{sh}}.$$

The value of the total E. M. F. generated by the dynamo is

$$E' = E + I' r_a$$

from which it may be seen by inspection that the lost volts in the armature $E' - E$, increase directly with I'. If E' and r_a are considered as remaining constant, then an increase in I' increases $I'r_a$ also, and E must become less. If E is decreased and E' is

constant then their difference which is equal to the lost volts in the armature must increase.

As $I' = I + I_{sh}$, we have by multiplying by r_a and substituting for $I'r_a$ its value $E' - E$,

$$E' = E + Ir_a + I_{sh}\, r_a = E + \frac{E}{R}\, r_a + \frac{E}{r_{sh}}\, r_a$$

$$= E \left\{ 1 + \frac{r_a}{R} + \frac{r_a}{r_{sh}} \right\} = E \times r_a \left\{ \frac{1}{r_a} + \frac{1}{R} + \frac{1}{r_{sh}} \right\}$$

The **electrical efficiency** of the dynamo is equal to the value of the useful energy divided by the total energy developed in the armature, the total energy itself being equal to the useful energy plus the energy lost in the armature, plus the energy lost in the field coils. Therefore the electrical efficiency is

$$\eta_e = \frac{E\, I}{E'\, I'} = \frac{I^2\, R}{I^2\, R + I'^2\, r_a + I^2_{sh}\, r_{sh}}$$

As $I' = I \times \dfrac{R + r_{sh}}{r_{sh}}$, and $I_{sh} = \dfrac{I\, R}{r_{sh}}$ we obtain

$$\eta_e = \frac{I^2\, R}{I^2\, R + \left\{ I \times \dfrac{R + r_{sh}}{r_{sh}} \right\}^2 r_a + \left\{ \dfrac{I\, R}{r_{sh}} \right\}^2 r_{sh}}$$

$$\eta_e = \frac{I^2\, R}{I^2\, R + \left\{ \dfrac{I^2\, R^2 + 2\, I^2\, R\, r_{sh} + I^2\, r^2_{sh}}{r^2_{sh}} \right\} r_a + \dfrac{I^2\, R^2}{r_{sh}}}$$

$$= \frac{1}{1 + 2\, \dfrac{r_a}{r_{sh}} + \dfrac{r_a}{R} + \dfrac{(r_a + r_{sh})\, R}{r^2_{sh}}}$$

By a mathematical analysis it can be proven that the value of η_e is a maximum when

$$R = r_{sh} \sqrt{\frac{r_a}{r_a + r_{sh}}}$$

This equation shows what the resistance of the outside circuit of a dynamo should be, knowing the shunt and armature resistances, in order to have the machine carry the proper load for maximum electrical efficiency.

Replacing R by its value in terms of r_a and r_{sh} we have the terms

$$\frac{R\,(r_{sh}+r_a)}{r^2_{sh}} = \frac{r_{sh}+r_a}{r_{sh}}\sqrt{\frac{r_a}{r_a+r_{sh}}} = \frac{\sqrt{r_a\,(r_{sh}+r_a)}}{r_{sh}}$$

and $$\frac{r_a}{R} = \frac{r_a}{r_{sh}}\sqrt{\frac{r_a+r_{sh}}{r_a}} = \frac{\sqrt{r_a\,(r_a+r_{sh})}}{r_{sh}}$$

The equation of the maximum efficiency of a shunt dynamo becomes

$$\eta_{e.Max.} = \frac{1}{1+2\frac{\sqrt{r_a\,(r_a+r_{sh})}}{r_{sh}}+2\frac{r_a}{r_{sh}}}$$

The value of the armature resistance compared with the value of the shunt resistance is always so small that $r_a + r_{sh}$ may be written r_{sh} without any appreciable error and the value of $\frac{r_a}{r_{sh}}$ is so small that it may be neglected, then the approximate value of the electrical efficiency of the shunt dynamo may be written in very simple terms and may be considered as equal to

$$\eta_e = \frac{1}{1+2\sqrt{\frac{r_a}{r_{sh}}}}$$

and the approximate ratio of the shunt resistance to the armature resistance is expressed by the formula

$$\frac{r_{sh}}{r_a} = \left\{\frac{2\,\eta_e}{1-\eta_e}\right\}^2$$

The following table from Wiener gives the necessary ratios of the resistance of the shunt field to the resistance of the armature for various electrical efficiencies for shunt dynamos. As these values are not given in ohms but only as ratios they hold good for all shunt dynamos, large or small. It will be noted that this electrical efficiency may be as near 100% as is desired, from a theoretical standpoint, but the limit is generally governed by the practical consideration of the cost. If the armature resistance is made too small, more copper is used to carry the current than is required, and if the field coil resistance is made extremely high the wire will be very small and very expensive.

TABLE GIVING RATIO OF SHUNT TO ARMATURE RESISTANCE FOR VARIOUS ELECTRICAL EFFICIENCIES FOR SHUNT DYNAMOS.

Electrical Efficiency.	Ratio of Shunt to Armature Resistance.	Electrical Efficiency.	Ratio of Shunt to Armature Resistance.
$100 \times \eta_e$	$\frac{r_{sh}}{r_a}$	$100 \times \eta_e$	$\frac{r_{sh}}{r_a}$
80%	64	96	2,304
85	128	97	4,182
90	324	98	9,604
93	706	99	39,204
95	1,444	99.5	158,404

The *commercial efficiency* is the ratio of the output to the energy supplied; or

$$\text{commercial efficiency} = \frac{\text{useful power}}{\text{total power}} = \frac{EI}{EI + I_{sh}^2 r_{sh} + I'^2 r_a + \text{stray power}}$$

As explained in a previous article, the *stray power* losses are made up of friction, eddy current and hysteresis losses. The stray power can be determined only by testing the dynamo.

In the *series-wound dynamo* there is but one circuit (see Fig. 40), and therefore but one current, I, the value of which

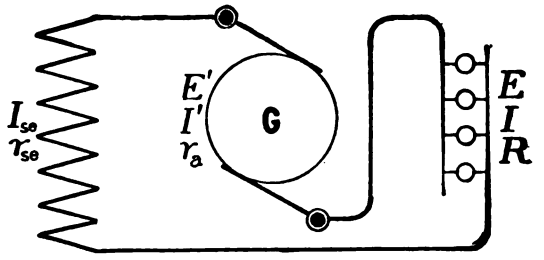

Fig. 40. Diagram of Series-Wound Dynamo.

depends upon the value of the total voltage E' and the total resistance, which is made up of r_a, r_{se} and R. The series field is com-

posed of a comparatively few turns of heavy copper conductor and is connected in series with the armature and the external circuit.

The current may be expressed as

$$I' = I_{se} = I$$

$$I' = \frac{E'}{R + r_a + r_{se}}$$

$$I = \frac{E + (E' - E)}{R + (r_a + r_{se})} = \frac{E}{R} = I'$$

$$I_{se} = \frac{E' - E}{r_{se} + r_a} = I = I'$$

The total voltage may be expressed as

$$E' = E + I(r_a + r_{se}) = E\left\{1 + \frac{r_a + r_{se}}{R}\right\}$$

The electrical efficiency is

$$\eta_e = \frac{\text{useful energy}}{\text{total energy}} = \frac{E\,I}{E'\,I'} = \frac{E}{E'}$$

or in terms of resistances it may be expressed as

$$\eta_e = \frac{I^2 R}{I'^2 (R + r_a + r_{se})} = \frac{R}{R + r_a + r_{se}}$$

From the equation $I' = \frac{E'}{R + r_a + r_{se}}$ it is seen that an increase in the outside resistance diminishes the current in the field coils, thus diminishing the magnetic flux. As the constancy of the magnetic flux depends upon the constancy of the current value these series-wound dynamos are best adapted to give a constant current, and are used mostly for running arc lamps on series circuits.

From the equation $E' = E + I(r_a + r_{se})$ it is seen that the total current in the armature is the same as the current in the outside circuit, also that the total voltage is the external voltage plus the lost voltage in the armature and series coils due to the passage of the current.

The **Compound-Wound Dynamo** (see diagrams Figs. 9 and 10) may be considered as a shunt dynamo to which some series windings have been added to compensate for the fall in voltage at

the brushes due to the demagnetizing effects of the armature, lost volts in armature, and to compensate for line losses as the load increases. The shunt circuit may either be connected to the brushes, in which case the machine is called the **Ordinary or Short Shunt Compound Dynamo** (see Fig. 9), or the shunt circuit may be connected to the terminals of the outside circuit in which case the machine is called a **Long Shunt Compound Dynamo** (see Fig. 10). Using the symbols as marked on these diagrams the equations for the ordinary or short shunt compound dynamo will be deduced. The total current is

$$I' = I + I_{sh} = I_{se} + I_{sh} = I + \frac{E + Ir_{se}}{r_{sh}}$$

It may also be written (see similar equation on page 66)

$$I' = \frac{E'}{r_a + \frac{(R + r_{se}) \times r_{sh}}{R + r_{se} + r_{sh}}}$$

or again it may be written

$$I' = I\left\{1 + \frac{R + r_{se}}{r_{sh}}\right\} = I \times \frac{r_{sh} + r_{se} + R}{r_{sh}}$$

The value of the shunt current may be written

$$I_{sh} = \frac{E' - I'r_a}{r_{sh}} = \frac{E + Ir_{se}}{r_{sh}} = I \times \frac{r_{se} + R}{r_{sh}}$$

The value of the total E. M. F. generated may be written

$$E' = E + I'r_a + Ir_{se}$$
$$= E + \left\{I + \frac{E + Ir_{se}}{r_{sh}}\right\} r_a + Ir_{se}$$

The value of the total E. M. F. generated may also be expressed in terms of the useful voltage and the various resistances. It is equal to the sum of four lost voltages. The first of these voltages is E, the useful voltage. The next is the voltage lost in the series coil and is equal to $\frac{r_{se}}{R} \times E$.

Then the total voltage at the brushes is

$$E + \frac{r_{se}}{R} E \quad \text{or} \quad E\left\{1 + \frac{r_{se}}{R}\right\} \quad \text{or} \quad E\left\{\frac{R + r_{se}}{R}\right\}$$

The lost voltage in the armature due to that part of the current that flows through the series and outside circuit is to the voltage of the series and outside circuit as the resistance of the armature is to the resistance of the series and outside circuit.

$$\text{Lost volts in armature due to outside current}: E\left\{\frac{R+r_{se}}{R}\right\} :: r_a : r_{se}+R$$

$$\text{Lost volts in armature due to outside current} = E\left\{\frac{r_a\,(R+r_{se})}{R\times(r_{se}+R)}\right\}$$

Similarly the lost voltage in the armature due to the current flowing in shunt field is to the voltage of the shunt field as the resistance of the armature is to the resistance of the shunt field.

$$\text{Lost volts in armature due to shunt current}: E\left\{\frac{R+r_{se}}{R}\right\} :: r_a : r_{sh}$$

$$\text{Lost volts in armature due to shunt current} = \frac{E\,(R+r_{se})\,r_a}{R\times r_{sh}}$$

Therefore, the total voltage generated being equal to the sum of these four expressions it may be written

$$E' = E + \frac{Er_{se}}{R} + \frac{E\,(R+r_{se})\,r_a}{R\,(r_{se}+R)} + \frac{r_a\,(R+r_{se})\,E}{r_{sh}\times R}$$

As the third term when simplified has the same denominator as the second term the two may be combined, and as all four terms in the right hand side of the equation contain E it may be taken outside the parenthesis ; then,

$$E' = E\left\{1+\frac{r_{se}+r_a}{R}+\frac{r_a\,(R+r_{se})}{R\times r_{sh}}\right\}$$

The electrical efficiency of the ordinary compound dynamo is equal to the useful energy divided by the sum of the useful energy in the outside circuit, plus energy lost in series coils, plus energy lost in shunt coils, plus energy lost in armature.

$$\eta_e = \frac{E\,I}{E'\,I'} = \frac{I^2\,R}{I^2\,R + I^2\,r_{se} + I_{sh}^2\,r_{sh} + I'^2\,r_a}$$

$$= \frac{I^2\,R}{\frac{I^2\,(r_{se}+r_{sh}+R)^2 r_a}{r_{sh}^2} + \frac{I^2\,(r_{se}+R)^2}{r_{sh}} + I^2\,R + I^2 r_{se}}$$

$$= \frac{1}{\frac{(r_{se}+r_{sh}+R)^2 r_a}{r_{sh}^2\,R} + \frac{(r_{se}+R)^2}{r_{sh}\,R} + 1 + \frac{r_{se}}{R}}$$

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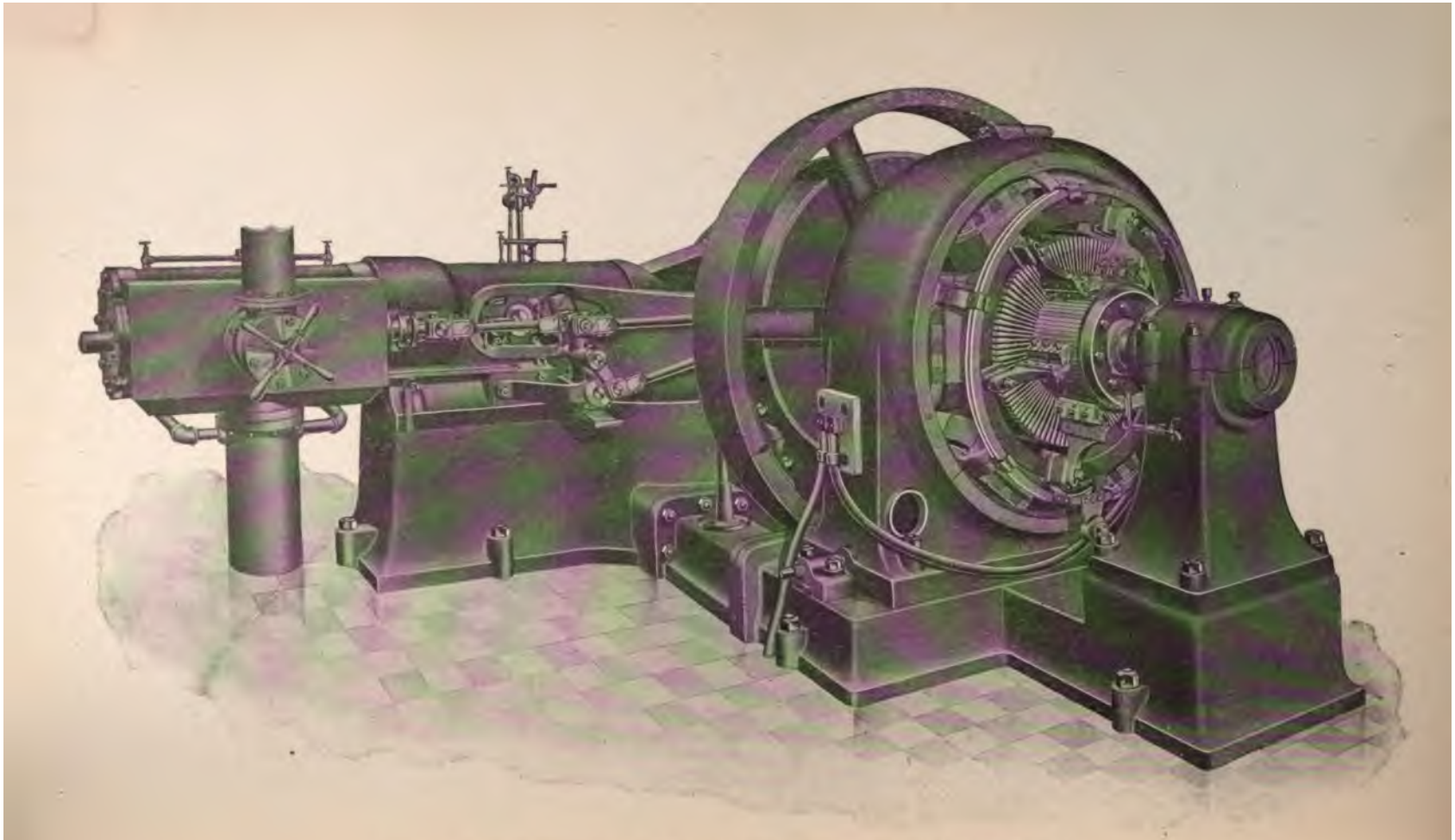

HEAVY DUTY, SIMPLE ENGINE DIRECT CONNECTED TO D. C. GENERATOR.

Buckeye Engine Company

For the Long Shunt Compound-Wound Dynamo (see Fig. 10) the equations may be written in a similar manner. The values of the total current generated will be

$$I' = I_{se} = I + I_{sh} = I + \frac{E}{r_{sh}} = I\frac{r_{sh} + R}{r_{sh}}$$

$$I_{sh} = \frac{E}{r_{sh}} = I\frac{R}{r_{sh}}$$

The total voltage generated in the armature is

$$E' = E + I'(r_a + r_{se}) = E + \left\{ I + \frac{E}{r_{sh}} \right\}(r_a + r_{se})$$

$$= E\left\{ 1 + \frac{R + r_{sh}}{R\, r_{sh}} \right\}(r_a + r_{se})$$

The electrical efficiency of the long shunt compound dynamo is

$$\eta_e = \frac{I^2 R}{I'^2 (r_a + r_{se}) + I_{sh}^2 r_{sh} + I^2 R}$$

$$= \frac{I^2 R}{\left\{ I^2 + \frac{2RI^2}{r_{sh}} + \frac{R^2 I^2}{r_{sh}^2} \right\}(r_a + r_{se}) + \frac{I^2 R^2}{r_{sh}} + I^2 R}$$

$$= \frac{1}{\frac{r_a + r_{se}}{R} + 2\left\{ \frac{r_a + r_{se}}{r_{sh}} \right\} + \frac{R(r_a + r_{se})}{r_{sh}^2} + \frac{R}{r_{sh}} + 1}$$

NOTE.

DESIGN OF DYNAMOS.

The complete calculations for the design of a dynamo are very long and involved. Besides calling for considerable judgment on the part of the designer, they require the use of a number of constants whose values must be known from previous experience or must be determined by testing the machine itself after completion. The most difficult part of the calculation is the assignment of the proper values to these constants.

In the following pages are given the electrical and magnetic details for the design of a 50-kilowatt shunt dynamo. The method is taken from Mr. A. E. Wiener's "Dynamo Electric Machines," and the constants from tables in that work, to which the reader is referred for further details. Though in general a 50-kilowatt machine should be made multipolar, the bipolar type is here chosen. The method is better illustrated and the calculations are simpler. For the multipolar machine the principle is the same, but the details differ somewhat.

The dynamo is a machine for converting mechanical into electrical energy, and must therefore be designed from the mechanical point of view as well as the electrical. Armature, shaft, bearings and pulley are therefore subject to the ordinary rules for machine design; and experience indicates that very conservative design is necessary in the parts subject to mechanical stresses. The following section, however, is limited to the electrical and magnetic parts of the design.

Calculation of a Bipolar, Single Magnetic Circuit, Smooth-Drum, High-Speed Shunt Dynamo.

50 K.W. Upright Horseshoe Type. Wrought-Iron Cores and Yoke, Cast-Iron Polepieces.

250 Volts. 200 Amperes. 1050 Revs. per Min.

(*a*) Calculation of Armature.

1. Length of Armature Conductor.

An electromotive force of one volt is generated by a conductor that cuts 100,000,000 C. G. S. lines of force per second. As the English system of units is still the standard in this country, one foot will be taken as the unit length of conductor, one foot per second the unit linear velocity, and one magnetic line of force per square inch as the unit field strength. Then every foot (12 in.) of inductor, moving at the rate of one foot (12 in.) per second in a field having one magnetic line of force per square inch will generate an E. M. F. of

$$\frac{12 \times 12 \times 1}{100{,}000{,}000} = \frac{144}{10^8} \text{ volt.}$$

As the armature of an ordinary bipolar dynamo has two parallel conductors each generating the same E. M. F.; and as these conductors are in parallel, two feet of conductor will be used in generating 144×10^{-8} volt or in other words each foot of the total length of conductors will generate only 72×10^{-8} volt if moving at unit velocity in unit field.

As this theoretical value of "unit armature induction" assumes that there is a magnetic field entirely surrounding the armature, it will have to be modified so as to take into account the fact that the fringe of magnetic lines from the pole pieces only partially surround the armature. For a 50 K.W. bipolar dynamo with smooth-drum armature the polar arc (see Figure 1) may be taken for the present as about 124°. It is found from actual practice that for a machine having a polar arc of about 124°, the

unit armature induction will not be the theoretical value of 72×10^{-8} but will be about

$$e = 61 \times 10^{-8} \text{ volts.}$$

The "specific armature induction," *i. e.*, the induction per unit length of conductor moving at velocity v_c, in a magnetic field of strength, $\mathfrak{C}''$ will be

$$e' = e \times v_c \times \mathfrak{C}'' \text{ volts.}$$

where e' = specific induction of active armature conductor, in volts per foot of conductor;

e = unit armature induction per pair of armature circuits in volts per foot of conductor;

v_c = conductor-velocity, or cutting speed, in feet per second;

$\mathfrak{C}''$ = field density, in magnetic lines of force per square inch.

It is customary to take the conductor velocity v_c, as about 50 feet per second for a 50 K.W. bipolar dynamo having a drum armature; also to take the field density $\mathfrak{C}''$ as about 22,000 if the machine has cast iron pole pieces. Therefore the value of e' may be written,

$$e' = \frac{61 \times 50 \times 22{,}000}{100{,}000{,}000} = \frac{671}{1{,}000}$$

Knowing the specific armature induction, e', the voltage induced by one foot of conductor, and knowing the voltage, E', that the armature is required to induce, one may easily find the total length of *active* wire, L_a, of the armature.

$$L_a = \frac{E'}{e'} = \frac{E' \times 10^3}{671}$$

where L_a = total length of active conductor (on whole circumference opposite pole pieces);

E' = total E. M. F. to be generated in armature; *i. e.*, volt output plus additional volts to be allowed for drop due to internal resistance.

For a dynamo of 50 K.W. capacity it is necessary to add about 6% to the value of E, the voltage wanted by the external circuit, in order to get E', the total E. M. F. to be generated in the armature. If E is 250, E' is 106% of 250 or 265, and

$$L_a = \frac{265 \times 10^3}{671} = 395 \text{ feet of } \textit{active} \text{ conductor.}$$

The part of the conductor passing over the ends of the armature core is not active in cutting lines of magnetic force and so this

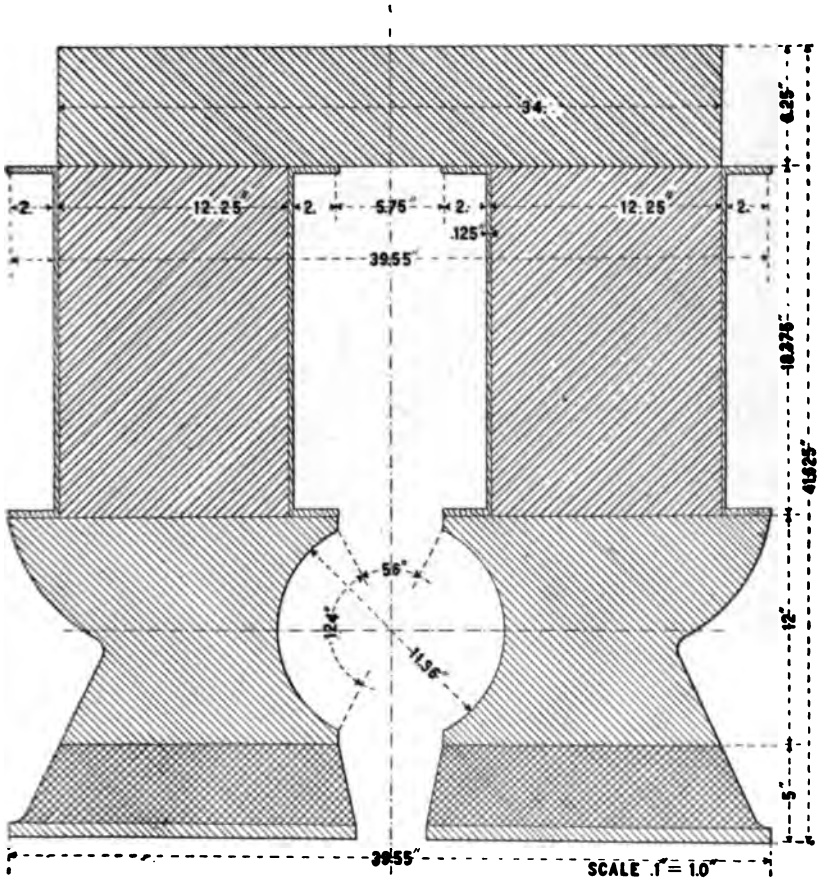

Fig. 1. Magnetic Circuit of 50 K.W. Dynamo.

length of conductor will have to be increased when the dimensions of the iron core of the armature are known.

2. Sectional Area of Armature Conductor, and Selection of Wire.

The cross section of wire to be chosen should be large enough so as not to be unduly heated by the current it has to carry. It is well to allow about 600 circular mils of copper conductor to 1

ampere of current, which is a current density of about 2,100 amperes per square inch of copper. Therefore to get the number of circular mils of copper to be provided multiply 600 by the current to be generated. There is to be furnished to the outside circuit 200 amperes. The armature will have to furnish this plus the current that goes through the shunt field. This latter value is so small however that it may be omitted with only trifling error or one may choose slightly larger wire for the armature than is needed for the 200 amperes. The cross section of conductor required therefore will be

200×600 circular mils or 120,000 circular mils.

As there are two conductors to carry this current each conductor should have 60,000 circular mils. By reference to the B. & S. wire table on page 28 it will be seen that No. 2 wire has a cross section of 66,371 circular mils.

As No. 2 wire is too stiff to wind on the armature, however,

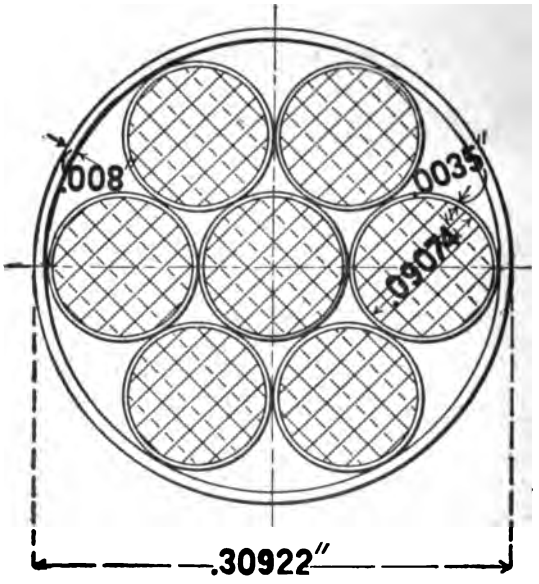

Fig. 2. Armature Conductor.

a cable made up of seven strands of No. 11 wire, having a copper cross section of $7 \times 8{,}234$ circular mils or a total of 57,638 circular mils is used. This will be a little higher current density than

ENGINE-TYPE GENERATORS

in Republic Rubber Works, Youngstown, Ohio.
Bullock Electric Manufacturing Co.

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was calculated upon at first but is not at all excessive. The diameter of No. 11 B. & S. wire is .09074 inch and a single cotton insulation of .007 inch is put on each strand and the seven strands are covered with a double cotton insulation of .016 inch. This will give the cable composed of seven strands of No. 11 B. & S. insulated wire a diameter (see Fig. 2) of

$$\delta'_a = 3 \times (.09074 \text{ inch} + .007 \text{ inch}) + .016 \text{ inch}$$
$$= .30922 \text{ inch.}$$

3. Diameter of Armature Core.

If the speed N is 1,050 revolutions per minute or $\frac{1050}{60}$ per second, and d'_a is the mean diameter of the armature winding in inches, or $\frac{d'_a}{12}$ in feet, then the cutting speed of the conductor in feet per second will be represented by,

$$v_c = \frac{d'_a \times \pi}{12} \times \frac{N}{60}$$

or

$$d'_a = \frac{12 \times 60}{\pi} \times \frac{v_c}{N} = \frac{12 \times 60 \times 50}{\pi \times 1050} = 10.91''.$$

It is found from actual practice that the ratio of the diameter of the armature, d_a, to the mean diameter of the armature

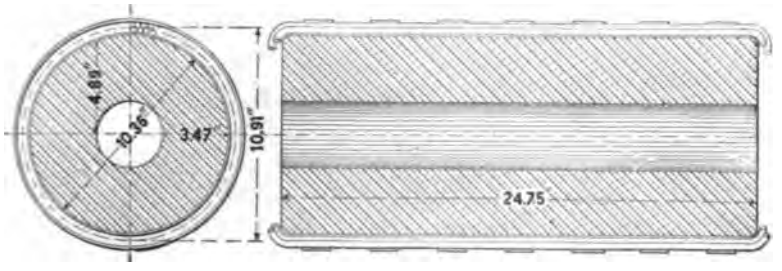

Fig. 3. Details of Armature.

winding, d'_a, is about .95 for drum armatures between eight and ten inches in diameter. Therefore (see Fig. 3)

d_a = .95 of 10.91 inches, or **10.36 inches.**

4. Length of Armature Core.

Knowing the number of conductors that can be laid on the surface of the armature core, and the available depth for the windings, one may easily determine the number of conductors that can be wound on the armature; and knowing this and the length of active armature conductor, the length of the armature core may be determined. For a machine generating less than 300 volts and having a drum armature of the size of the one under consideration about 8% of the surface of the armature core is given up to division strips or driving horns.

$$\text{Then } n_w = \frac{.92 \times d_a \times \pi}{\delta_a'}$$

$$= \frac{.92 \times 10.36 \times \pi}{.30922} = 97 \text{ or } 96.$$

where n_w = the number of armature wires per layer;
d_a = the diameter of the armature core, in inches;
δ'_a = the width of insulated armature conductor, in inches;
.92 = the portion of the surface to be occupied by the conductors.

For a drum armature of the size of the one under consideration the height of the windings should be about .55 of an inch and of this space about .06 inch will be taken up by the insulation between windings and the armature, and .05 inch by binding wires. This leaves a net height of about .44 of an inch for the conductor. Then the number of layers of conductors will be

$$n_l = \frac{h'_a}{\delta''_a} = \frac{.44}{.30922} = 1\tfrac{1}{2} \text{ or } 2$$

where n_l = number layers of armature wire;
h'_a = net height of winding space, in inches;
δ''_a = height of insulated conductor, in inches.

By dividing the length of active armature conductor by the number of conductors we obtain the length of one active conductor which is the length of the armature core (see Fig. 3).

$$l_a = \frac{12 \times L_a}{n_w \times n_l} = \frac{12 \times 395}{96 \times 2} = 24\tfrac{3}{4} \text{ inches approx.}$$

where l_a = length of armature core parallel to pole faces, in inches;
L_a = length of active armature conductor in feet;
n_w = number of wires per layer;
n_l = number of layers of wire on armature.

5. Arrangement of Armature Windings.

For machines under 300 volts it is customary to have from 40 to 60 commutator segments. With this number of segments the voltage between two consecutive ones is low, and the pulsating current is within a fraction of one per cent of being a steady current. The number of commutator divisions, n_c, will be found by multiplying the number of wires per layer, n_w, by the number of layers, n_l, and dividing the product by some even number that gives a quotient which is between 40 and 60.

$$n_c = n_w \times n_l \div 4 = 48.$$

The number of convolutions per commutator segment, n_a will be

$$n_a = \frac{n_w \times n_l}{2 \times n_c} = \frac{96 \times 2}{2 \times 48} = 2$$

since it takes two conductors to make one turn. Therefore to sum up we have **48 coils,** each consisting of **2 turns** of a cable having **7 No. 11 B. & S. wires.**

6. Total Length of Armature Conductor, Weight and Resistance.

In order to connect the ends of the active conductors, turn the corners, etc., for this drum armature the total length of armature conductor will need to be about $1\frac{3}{4}$ times the active conductor.

$$L_t = 1.75 \times L_a = 1.75 \times 395 \text{ feet} = \textbf{691 feet.}$$

The weight of the conductor will be as follows: — A copper wire .001 in diameter weighs .00000303 pounds per foot of length. Therefore the weight of the total length of the copper in the armature conductor would be

$$wt_a = k_5 \times L_t \times \delta_a^2 \times .00000303$$
$$= 1.03 \times 691 \times 57638 \times .00000303 = \textbf{124 pounds}$$

where wt_a = weight of bare armature winding in pounds;

k_5 = ratio between weights of the insulated wire and bare wire;

L_t = total length of armature conductor in feet;

δ_a^2 = area of conductor in circular mils.

The **resistance** of the armature will be as follows: — The total length of armature wire 691 feet is arranged in two parallel

circuits 345½ feet long. These two paths are each composed of seven No. 11 B. & S. wires.

The resistance of 1,000 feet of No. 11 B. & S. wire is 1.311 ohms.

Therefore the resistance of the armature is,

$$R_a = \frac{1}{2 \times 7} \times \frac{345.5}{1{,}000} \times 1.311 \text{ ohms} = \textbf{.0324 ohm.}$$

7. Radial Depth of Armature Core, Minimum and Maximum Cross Section, and Average Magnetic Density of Armature Core.

The following formula determines the proper size for the necessary strength of the armature shaft where it passes through the iron core of the armature.

$$d_c = k_9 \times \sqrt[4]{\frac{P'}{N}} = 1.3 \times \sqrt[4]{\frac{50{,}000}{1{,}050}} = \textbf{3.42 inches.}$$

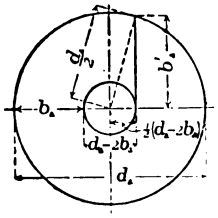

Fig. 4.

where d_c = diameter of armature shaft at core in inches;
P' = capacity of machine in watts;
N = speed, in revolutions per minute;
k_9 = constant depending upon capacity of machine.

Therefore the breadth of armature cross section, or radial depth of armature core is

$$b_a = \frac{1}{2}(d_a - d_c) = \frac{10.36 - 3.42}{2} = \textbf{3.47 inches.}$$

where b_a = radial depth of armature core, in inches;
d_a = diameter of armature core, in inches;
d_c = diameter of core section of armature shaft.

The maximum depth of armature core (see Fig. 4) is,

$$b'_a = \sqrt{\frac{d_a^2}{4} - \frac{(d_a - 2b_a)^2}{4}}$$

$$= \sqrt{\frac{(10.36)^2}{4} - \frac{(3.42)^2}{4}} = \textbf{4.89 inches.}$$

The cross section of the magnetic field in the armature is equal to

$$S''_{a1} = 2 \times l_a \times b_a \times k_2$$
$$= 2 \times 24.75 \times 3.47 \times .95 = \textbf{163 square inches.}$$
$$S''_{a2} = 2 \times l_a \times b'_a \times k_2$$
$$= 2 \times 24.75 \times 4.89 \times .95 = \textbf{230 square inches.}$$

where S''_{a1} = minimum cross section of armature core, in square inches;

S''_{a2} = maximum cross section of armature core, in square inches;

l_a = length of armature core, in inches;

b'_a = radial depth of armature core, in inches;

k_2 = ratio of net iron section to total cross section of armature core.

The useful magnetic flux in the armature may be obtained as follows: The

$$\text{E. M. F.} = \frac{\text{Number of C. G. S. lines cut per second}}{10^8}$$

$$E' = \frac{N \times N_c \times \Phi}{60 \times 10^8} \text{ volts}$$

where E' = total E. M. F. induced in armature;

N = number of armature revolutions per minute;

N_c = total number of conductors all around pole facing surface of armature;

Φ = total number of useful magnetic lines, in webers

$$\text{or} \quad \Phi = \frac{60 \times 10^8 \times E'}{N \times N_c}$$
$$= \frac{60 \times 10^8 \times 265}{1050 \times 192} = \textbf{7,886,905 webers.}$$

Therefore the density of magnetic lines per square inch at the minimum cross section of the armature core is

$$\mathfrak{B}''_{a1} = \frac{7,886,905}{163} = \textbf{48,386 lines} \text{ per square inch.}$$

and the density at the maximum cross section is

$$\mathfrak{B}''_{a2} = \frac{7,886,905}{230} = \textbf{34,291 lines} \text{ per square inch.}$$

Next we wish to find the number of ampere-turns required to furnish this induction. The law for the magnetism in a magnetic circuit is exactly similar to the law for current in an electric circuit.

$$\text{Current (or Electric Flux)} = \frac{\text{Electromotive Force}}{\text{Resistance}}.$$

$$\text{Magnetic Flux} = \frac{\text{Magnetomotive Force}}{\text{Reluctance}}.$$

Therefore the

$$\text{Magnetomotive Force} = \text{Magnetic Flux} \times \text{Reluctance}.$$

As the resistance of an electric circuit can be expressed by the specific resistance or resistivity of the material multiplied by the length of circuit and divided by the cross section, so the reluctance of a magnetic circuit can be expressed by the specific reluctance or reluctivity of the material multiplied by the length of the circuit and divided by the cross section. Therefore the

$$\text{Reluctance} = \text{Reluctivity} \times \frac{\text{Length}}{\text{Area}}.$$

As the conductivity of an electric circuit is the reciprocal of the resistivity, so the permeability of a magnetic circuit is the reciprocal of the reluctivity. Therefore the

$$\text{Reluctance} = \frac{\text{Length}}{\text{Permeability} \times \text{Area}}.$$

or

$$\text{Magnetomotive Force} = \frac{\text{Magnetic Flux} \times \text{Length}}{\text{Permeability} \times \text{Area}}.$$

and since the magnetic flux divided by the area is the magnetic density the formula is simplified by writing

$$\text{Magnetomotive Force} = \frac{\text{Magnetic Density} \times \text{Length}}{\text{Permeability}}.$$

The Unit of Field Density, or the magnetic density caused by a unit pole, is 1 line of magnetic force per square centimeter of field area and is termed 1 gauss.

A single Line of Force, or the Unit of Magnetic Flux, is that amount of magnetism that passes through every square centimeter of cross section of a magnetic field whose density is unity, and is termed 1 weber.

The unit magnetic pole, or the pole of unit strength is that which repels an equal pole at unit distance with unit force. The lines of force are straight lines from the center of the sphere to the surface, there being one line to each square centimeter area on the surface. As the surface of a sphere having a radius of 1 centimeter has an area of 4π square centimeters, it follows that from a pole of unit strength there is a magnetic flux of 4π C. G. S. lines of magnetic force or 4π webers or 12.5664 webers.

One absolute C. G. S. unit of current, which is 10 times as large as the ampere, or ten amperes, flowing in a wire which is bent into a circle of one centimeter radius gives a C. G. S. unit magnetic pole at the center of curvature or 12.5664 webers. One practical unit or 1 ampere would cause one tenth as many webers or 1.25664 webers.

A long solenoid having a cross section of one square centimeter having 1 ampere ($\frac{1}{10}$ of the C. G. S. unit current) flowing per unit length of coil, has poles of $\frac{1}{10}$ unit strength which causes a magnetic flux of $\frac{1}{10} \times 4\pi$ webers.

The density of the magnetic circuit is $\frac{4\pi}{10}$ webers per square centimeter or $\frac{4\pi}{10}$ gausses.

The reluctance of unit length of the solenoid of one square centimeter cross section for air is unity or 1 oersted. The magnetomotive force is the product of the magnetic density, the reluctance and the length, and is measured in gilberts. Therefore the magnetomotive force required to produce a magnetic density of $\frac{4\pi}{10}$ gausses in a column of air one centimeter long and having a cross section of one square centimeter thus having a reluctance of 1 oersted is

$$\text{M. M. F.} = \frac{4\pi}{10} \times 1 \times 1 = \frac{4\pi}{10} \text{ gilberts.}$$

The magnetomotive force of $\frac{4\pi}{10}$ gilberts being produced by one ampere-turn, it follows that the

$$\text{Number of Ampere-turns} = \frac{10}{4\pi} \times \text{Number of Gilberts.}$$

The

Magnetizing Force = Specific Magnetizing Force × Length, or the

Number of Ampere-turns = Ampere-turns per unit of Length × Length,

or $a\,t = f\,(\mathfrak{B}'') \times l$

where $a\,t$ = Ampere-turns required to magnetize a portion of a magnetic circuit;

$\mathfrak{B}''$ = density of the magnetic circuit per square inch;

$f\,(\mathfrak{B}'')$ = Specific magnetizing force, in ampere-turns per inch of length for the particular material and density employed; (this value of the magnetizing force must be taken from some table or induction curve as shown in Fig. 5, or found by experiment for the particular piece of iron to be used);

l = length of magnetic circuit of the material in inches.

To get the number of ampere-turns required to overcome the reluctance of the armature it is necessary to modify the above formula a little, as the value of $\mathfrak{B}''$ is not constant in all parts of the core.

$$f\,(\mathfrak{B}''_a) = \frac{1}{2}\left\{f\,(\mathfrak{B}''_{a1}) + f\,(\mathfrak{B}''_{a2})\right\}$$

$$= \frac{f\,(48{,}386) + f\,(34{,}291)}{2} = \frac{9.2 + 6.4}{2} = 7.8$$

It takes as seen from Fig. 5 about 9.2 ampere-turns to magnetize 1 inch of wrought iron to a density of 48,386 lines, and 6.4 ampere-turns to magnetize it to a density of 34,291 lines. Also 7.8 ampere-turns correspond to a density of **41,500 lines.**

8. Energy Losses in Armature, and Temperature Increase.

The energy lost in the armature due to the current in the armature conductors is

$$P_a = 1.2 \times (k_6 \times I)^2 \times r_a$$
$$= 1.2 \times (1.03 \times 200)^2 \times .0324 = \textbf{1650 watts}$$

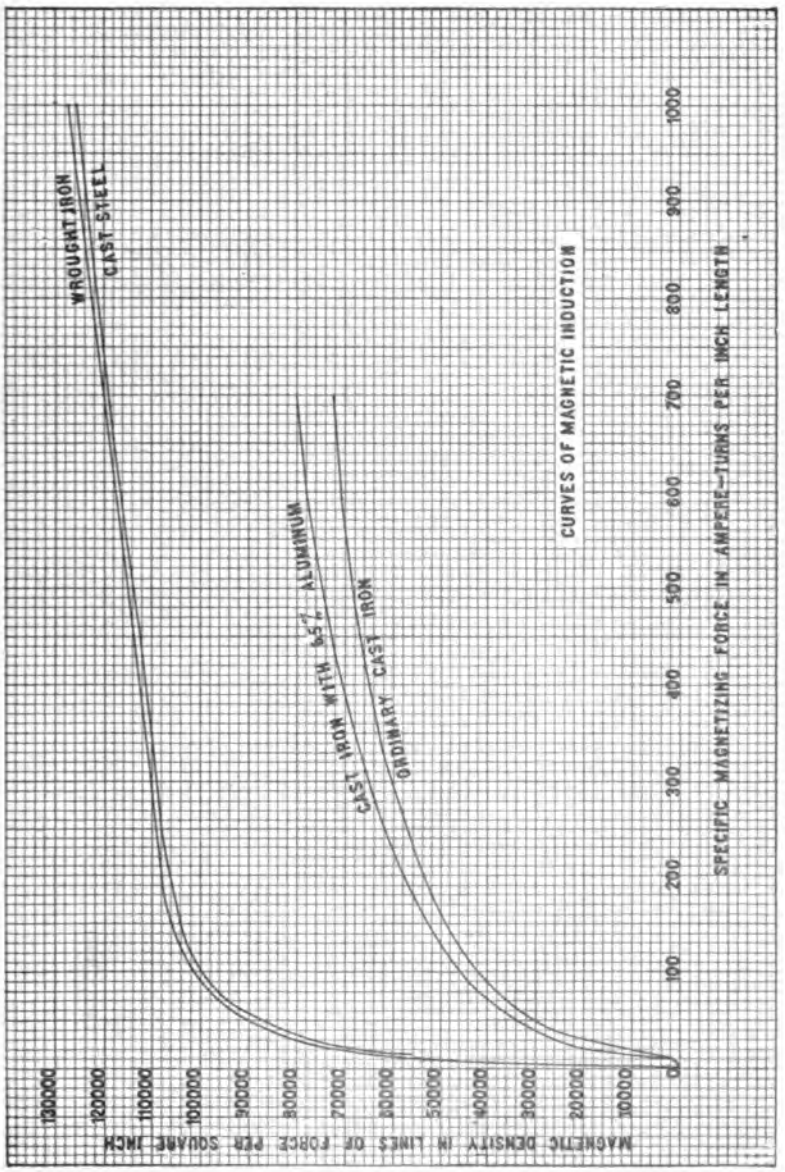
CURVES OF MAGNETIC INDUCTION
SPECIFIC MAGNETIZING FORCE IN AMPERE-TURNS PER INCH LENGTH
MAGNETIC DENSITY IN LINES OF FORCE PER SQUARE INCH
WROUGHT IRON
CAST STEEL
CAST IRON WITH 6.5% ALUMINUM
ORDINARY CAST IRON
0
100
200
300
400
500
600
700
800
900
1000
10000
20000
30000
40000
50000
60000
70000
80000
90000
100000
110000
120000
130000

Fig. 5.

where P_a = energy dissipated in armature winding, in watts;
r_a = resistance of armature winding cold, in ohms;
1.2 = ratio of resistance of armature winding hot, to resistance cold;
I = output of machine in amperes;
1.03 = ratio of total current generated to output.

The resistance of copper wire at 150° F. is about 1.2 times that at 60° F. The energy in the shunt coil of a 50 K.W. compound dynamo is about 3% of the output of the machine.

The loss in the armature core due to hysteresis is proportional to the 1.6th power of the magnetic density, directly proportional to the number of magnetic reversals, and directly proportional to the mass of the iron. Expressed in C. G. S. absolute units the energy consumed by hysteresis is,

$$P_h' = n_1 \times \mathfrak{B}_a^{1.6} \times N_1 \times M_1,$$
$$P_h' = n_1 \times \mathfrak{B}_a^{1.6} \times N_1 \times M_1',$$

where P'_h = energy lost due to hysteresis, in ergs;
n_1 = constant depending on magnetic hardness of material Hysteresis Resistance;
$\mathfrak{B}_a$ = density of lines per square centimeter of iron;
N_1 = frequency, or number of complete cyles of 2 reversals each, per second;
M_1' = mass of iron in cubic centimeters.

For soft sheet iron discs n_1 may be taken as .0035. In order to get the value of P_h' in practical units we must change the above equation. One watt equals 10^7 ergs. Instead of $\mathfrak{B}_a$ use the density $\mathfrak{B}_a''$ in lines per square inch.

$$N_1 = \frac{N}{60} = \frac{1050}{60} = 17\tfrac{1}{2}.$$

One cubic foot equals 28,316 cubic centimeters. The mass of iron in the armature in cubic feet is

$$M = \frac{d_a''' \times \pi \times b_a \times l_a \times k_2}{1{,}728}$$

$$\frac{(10.36 - 3.47) \times \pi \times 3.47 \times 24.75 \times .95}{1728} = 1.02 \text{ cubic ft.},$$

where M = net mass of iron, in cubic feet;

d_a''' = mean diameter of armature core, in inches,

$= d_a - b_a$, (see Fig. 4);

l_a = length of armature core, in inches;

b_a = radial depth of armature core, in inches;

k_2 = ratio of net iron section to total iron section.

There are 1,728 cubic inches in 1 cubic foot. Expressing the value of the energy lost by hysteresis in practical units we have,

$$P_h = 10^{-7} \times .0035 \times \left\{ \frac{\mathfrak{B}_a''}{6.45} \right\}^{1.6} \times 28{,}316 \times N_1 \times M,$$

where P_h = energy lost by hysteresis, in watts;

$\mathfrak{B}_a''$ = density, in lines per square inch, corresponding to average magnetizing force required for armature core, (1 square inch = 6.45 square centimeters);

N_1 = frequency, in cycles per second;

M = net mass of iron in armature, in cubic feet.

By reducing the above expression to simple form, we have

$$P_h = 5 \times 10^{-7} \times \mathfrak{B}_a''^{1.6} \times N_1 \times M,$$

$$= 5 \times 10^{-7} \times (41{,}500)^{1.6} \times 17\tfrac{1}{2} \times 1.02 = 219 \text{ watts.}$$

Eddy Currents.

It has been explained under *Electromagnetic Induction* (see "Theory of Dynamo Electric Machinery") by what means and methods electromotive forces, and consequently electrical currents are set up in closed conductors. It is clear that any mass of metal moving in a field is a closed conductor. A loop of wire may have currents generated in it quite as easily if it be made part of a metallic disc as if it were still a loop. Since the lines of force can only cut a solid piece of metal once, the electromotive force that will be generated, unlike that in a coil of many turns cut by the same field, will be very small. But if the piece of metal be large the resistance will be very small so that the current which is induced may reach considerable strength and cause much heating. This action is largely prevented from taking place in the armature cores of dynamos by building them up of thin sheets of iron. The sheets are insulated from each other and are placed in such a

direction as to cut across the path which would be followed by the induced current. This method of construction is termed lamination, and it is necessary to build all iron or metallic parts which are not intended to act as conductors in this way, if they are likely to be subjected to fields of varying strength. This is the case in alternating current machinery and in the moving parts of direct current machinery. Sometimes even conductors, if they are very large, have local currents generated in them which are of course undesirable because they are a source of waste and heat, and it becomes necessary to laminate them. In this case the lamination would be parallel to the length of the conductor. Heavy conductors are usually laminated or stranded any way for greater ease in construction. Eddy currents are often called Foucault currents from Foucault who first called attention to their existence.

The energy lost by eddy currents is found to be proportional to the square of the magnetic density, to the square of the frequency, and to the mass. The equation for the lost energy due to eddy currents is,

$$P_e' = \epsilon' \times \mathfrak{B}_a^2 \times N_1^2 \times M'_1 ;$$

where P_e' = lost energy due to eddy currents, in ergs;
$\mathfrak{B}_a$ = density of lines of force, per square centimeter of iron;
N_1 = frequency, in cycles per second;
M_1' = mass of iron, in cubic centimeters;
ϵ' = eddy current constant, depending upon the thickness and the specific electric conductivity of the material;

$$\epsilon' = \frac{\pi^2}{6} \times \delta^2 \times \gamma \times 10^{-9}$$

$$= 1.645 \times \delta^2 \times \gamma \times 10^{-9}$$

where δ = thickness of sheet iron, in centimeters;
γ = electrical conductivity, in mhos;
γ = 100,000 for iron.

By changing to practical units and simplifying the above equation.

$$P_e = 10^{-7} \times 1.645 \times (2.54\ \delta_1)^2 \times 10^{-4} \times \left\{ \frac{\mathfrak{B}_a''}{6.45} \right\}^2 \times N_1^2$$

$$\times\ 28{,}316 \times M = 7.22 \times 10^{-8} \times \delta_1^2 \times \mathfrak{B}_a''^2 \times N_1^2 \times M.$$

where δ_1 = thickness of iron laminæ in armature, in fractions of an inch;

$\mathfrak{B}_a''$ = density, in lines per square inch, corresponding to average specific magnetizing force of armature core;

N_1 = frequency in cycles per second:

M = mass of iron, in cubic feet.

The terms 7.22, 10^{-8}, δ_1^2, and $\mathfrak{B}_a''^2$, may be multiplied together to form the eddy current factor ϵ, and then the formula for loss due to eddy currents becomes,

$$P_e = \epsilon \times N_1^2 \times M$$

$$= .0125 \times (17\tfrac{1}{2})^2 \times 1.02 = 4. \text{ watts.}$$

For $\epsilon = .0125$ when the thickness of the sheet iron discs is .01″ and when the magnetic density is 41,500 lines.

The total energy loss in the armature is

$$P_A = P_a + P_h + P_e = 1650 + 219 + 4$$

$$= 1873 \text{ watts} = 2.5 \text{ h. p.}$$

Knowing the amount of electrical energy lost in the armature and dissipated as heat, and knowing the dimensions and speed of the armature it is possible, by using certain known constants that have been found by experience, to calculate quite exactly the rise of temperature in the armature and to calculate the hot resistance of the copper in the armature conductors. These details are somewhat complicated and will not be treated.

(*b*) Dimensions of Magnet Frame.

1. Total Magnetic Flux, and Sectional Area of Magnet Frame.

The total magnetic flux to be generated in a dynamo is the useful magnetic flux multiplied by a factor of magnetic leakage. Knowing the shape of the various parts of the magnetic circuit and the reluctance of the parts of the magnetic circuit and the sur-

rounding air circuits, it is possible to determine the amount of magnetic leakage, or waste magnetism.

$$\Phi' = \lambda \times \Phi = 1.35 \times 7{,}886{,}905 = 10{,}647{,}322 \text{ webers}$$

where Φ' = total flux to be generated in dynamo, in lines of force;

Φ = useful flux necessary to produce the required E. M. F.;

λ = factor of magnetic leakage, which for a 50 K.W. bipolar machine of the Edison type is found to be about 1.35.

The sectional area of the magnet frame is expressed by the formula,

$$\mathcal{S}'''_m = \frac{\Phi'}{\mathfrak{B}''_m} = \frac{10{,}647{,}322}{90{,}000} = \textbf{118 square inches}$$

where $\mathcal{S}'''_m$ = cross section of wrought iron magnet core and of yoke, in square inches;

Φ' = total flux, in webers;

$\mathfrak{B}''_m$ = magnetic density of magnet frame, which for wrought iron magnet cores and yoke is taken as 90,000 lines per square inch.

The Practical Limit of Magnetization for cast iron pole pieces is taken as 50,000 lines per square inch.

$$\mathcal{S}'''_m = \frac{\Phi'}{\mathfrak{B}''_m} = \frac{10{,}647{,}322}{50{,}000} = \textbf{213 square inches.}$$

2. Sectional Area of Magnet Frame.

If the magnet core is in the form of a cylinder the diameter will be

$$d_m = \sqrt{\frac{4}{\pi} \times 118} = 12.25 \text{ inches.}$$

For a circular magnet core carrying about 10,000,000 lines of force the most economical ratio of length to diameter of magnet core is found to be about 1.5. Hence

$$l_m = 1.5 \times d_m = 18.375 \text{ inches.}$$

For a machine having an armature between 10 and 11 inches in diameter the distance, c, between magnet cores is taken as about

$$c = 5\tfrac{3}{4} \text{ inches.}$$

Take the width of the wrought iron yoke a little greater than

the diameter of the magnet cores so as to form a mechanical protection to them. Let this width be $18\frac{3}{4}$ inches. Then the height of the yoke would be

$$h_y = \frac{118}{18\frac{3}{4}} = 6\frac{1}{4} \text{ inches.}$$

The pole pieces are determined as follows: — The bore of the pole pieces is the sum of the diameter of the armature core, the winding, the insulation and binding, and the air gaps, which for a drum armature of this diameter is taken as about .14″.

$$\text{Diam. of bore} = 10.36'' + 4 \times .30922'' + 2 \times .11'' + .14'' = 11.96''.$$

In order to keep the corners of the pole pieces far enough apart so that there will not be too much leakage across, the distance is taken from 1.25 to 8 times the length of the two air gaps according to the size and type of dynamo.

$$l'_p = k_{11} \times (d_p - d_a) = 4. \times (11.86 - 10.36) = 6.00 \text{ inches.}$$

where l'_p = distance between pole corners, in inches;
d_p = diameter of bore of pole pieces, in inches;
d_a = diameter of iron core of armature, in inches;
k_{11} = 4. for drum armature of a 50 K.W. bipolar dynamo.

Let the length of the pole pieces equal the length of iron core in armature, or

$$l_p = 24\tfrac{3}{4}''.$$

Let the height of pole pieces equal the diameter of bore approx.

$$h_p = 12''.$$

The thickness at the center which carries only half the lines will be

$$\frac{213}{2 \times 24\frac{3}{4}} = 4.3 + \text{ or } 4\tfrac{3}{8}''.$$

In order to provide a non-magnetic base through which the magnetic lines will not leak from pole to pole a block of zinc about 5 inches thick should be placed under the dynamo.

(c) Calculation of Magnetizing Forces.

1. Air Gaps.

The length of the two air gaps is

$$l''_g = k_{12} \times (d_p - d_a) = 1.4 \times 1.5'' = 2.1''$$

where l''_g = length of path of magnetic lines across the two air gaps;

d_p = diameter of bore of pole pieces, in inches;

d_a = diameter of iron core of armature, in inches;

k_{12} = constant depending on the path of the lines of force through the air gap. The lines of force pass through the gaps obliquely owing to the distortion of the magnetic field and the constant, k_{12}, grows greater as the velocity of the conductor, v_c, and the density, $\mathfrak{B}$, are greater. If the product of v_c and $\mathfrak{B}$ is above 2,000,000 the value of k_{12} is taken as 1.4.

The cross section of the magnetic field of the air gap is represented by,

$$S_f = d_f \times \frac{\pi}{2} \times \beta'_1 \times l_f$$

$$= 11.11'' \times \frac{\pi}{2} \times .84 \times 24\tfrac{3}{4} = 363 \text{ square inches}$$

where S_f = the area occupied by the effective conductors, in square inches;

d_f = mean diameter of magnetic field in inches;

$= \frac{1}{2}(d_a + d_p)$;

l_f = breadth of magnetic field, in inches;

β'_1 = ratio of effective field circumference, depending upon the percentage of polar embrace, here taken as .84.

The actual field density in air gaps is found by dividing the value of the total useful flux in webers, by the area of the magnetic field of air gap.

$$\mathfrak{B}'' = \frac{\Phi}{S_f} = \frac{7,886,905}{363} = 21,727 \text{ lines per square inch.}$$

The number of ampere-turns required to produce this magnetic density in the air gaps is,

$$a\,t_g = \frac{10}{4\pi} \times \mathfrak{B}'' \times \frac{l''_g}{2.54} = .3133 \times \mathfrak{B}'' \times l''_g$$

$$= .3133 \times 21,727 \times 2.1 = \textbf{14,295 ampere-turns.}$$

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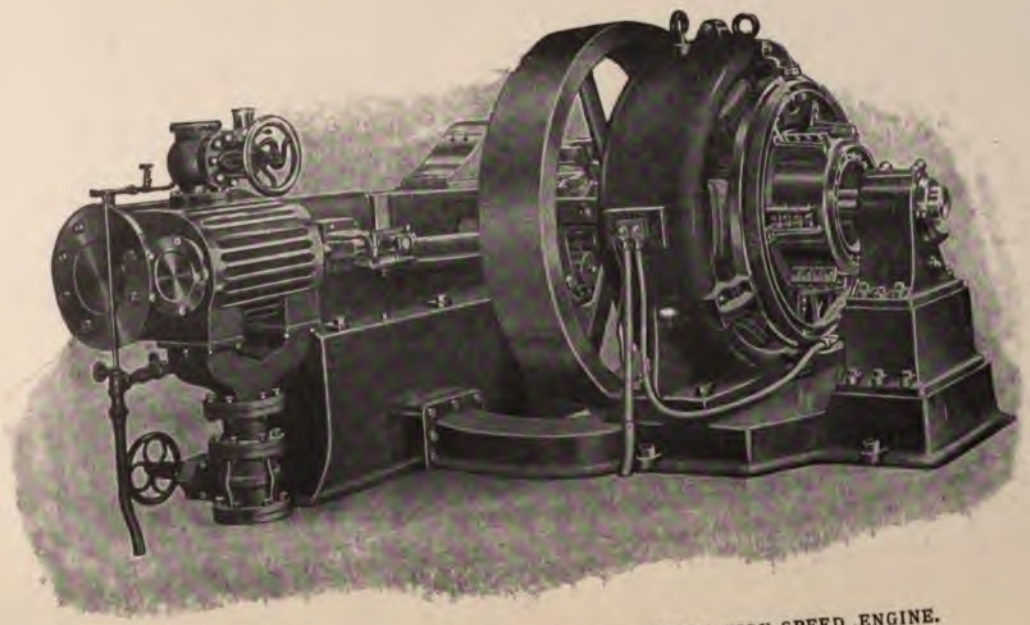
TILDEN FOUNDATIONS



100 K.W. ENGINE-TYPE GENERATOR AND AUTOMATIC HIGH-SPEED ENGINE.
Triumph Electric Company.

2. Armature Core.

The average length of the magnetic paths in the armature is (see Fig. 6).

$$l''_a = d'''_a \times \pi \times \frac{90° + a}{360°} + b_a$$

$$= 6.89'' \times \pi \times \frac{90 + 28}{360} + 3.47'' = \textbf{10.57 inches.}$$

where l''_a = length of magnetic path in armature core, in inches;
d'''_a = mean diameter of armature core, in inches;
b_a = radial depth of armature core, in inches;
a = half angle between adjacent pole corners.

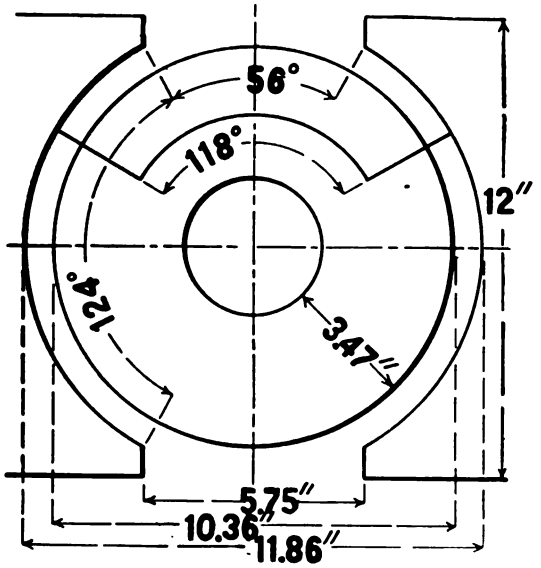


Fig. 6. Magnetic Details of Armature Core.

As previously determined the minimum cross section of the armature core is,

S''_{a1} = 163 square inches,

and the maximum cross section is

S''_{2a} = 230 square inches.

The average specific magnetizing force to magnetize the armature core to the required density will be

$$f(\mathfrak{B}''_a) = \frac{f(48{,}386) + f(34{,}291)}{2} = 7.8 \text{ ampere-turns.}$$

The total magnetizing force required to magnetize the armature is

$a\,t_a = 10.57 \times 7.8 =$ **82 ampere-turns.**

3. Wrought Iron Field Cores and Yoke.

The length of the magnetic path through the wrought iron cores and the yoke will be (see Fig. 1).

$l''_{w.i.} = 2 \times 18\frac{3}{4} + 6\frac{1}{4} + 18 =$ **61 inches.** (approx.)

The density of the field has already been decided upon as 90,000 lines per square inch. It has been determined by experiment that a specific density of 90,000 lines in wrought iron is produced by 50.7 ampere turns.

The total length of magnetic circuit through field cores and yoke will require

$a\,t_{w.i} = 61 \times 50.7 =$ **3093 ampere-turns.**

4. Cast Iron Pole Pieces.

The average length of the magnetic path through the pole pieces may be taken as the average of the longest path and the shortest path. In the present case it is about

$l''_{c.i.} = 15$ inches.

The minimum cross section at the center of the pole piece which carries only half the lines has already been taken as

$S_{c.i.1} = 106.5$ square inches

which corresponds to a density of

$\mathfrak{B}''_{c.i.} = 50{,}000$ lines per square inch.

The maximum cross section of the magnetic circuit in pole pieces is the area of the pole face and is

$$S_{c.i.2} = 11.86 \times \pi \times \frac{124}{360} \times 24.75 = 318 \text{ square inches,}$$

which corresponds to a minimum density of

$$\mathfrak{B}''_{c.i.2} = \frac{7{,}886{,}905}{318} = 24802 \text{ magnetic lines.}$$

The average specific magnetizing force will be

$$f(\mathfrak{B}''_{c.i.}) = \tfrac{1}{2}\,[f(50{,}000) + f(24{,}802)] = \frac{160 + 38.6}{2}$$

$= 99.3$ ampere-turns,

which corresponds to average density of 42,175 lines.

Then the total number of ampere-turns required to magnetize pole pieces is

$$a\,t_{c.i.} = 15 \times 99.3 = \textbf{1490 ampere turns.}$$

5. Armature Reactions.

The demagnetizing and cross-magnetizing effects caused by the ampere-turns of the armature oppose the magnetizing effect of the field coils and have to be overcome by adding more ampere-turns to those required to overcome the reluctance of the circuit.

The number of ampere-turns required to balance the armature reaction is,

$$a\,t_r = k_{14} \times \frac{N_a \times I'}{2} \times \frac{k_{13} \times a}{180^\circ}$$

$$= 1.71 \times \frac{96 \times 200}{2} \times \frac{28}{180} = \textbf{2554 ampere-turns}$$

where $a\,t_r$ = ampere-turns required to compensate for armature reactions;

k_{14} = being a constant depending upon the magnetic density in pole pieces;

N_a = total number of turns on armature;

I' = total armature current in amperes;

2 = number of armature circuits for current;

$k_{13} \times a$ = angle of brush lead, which is nearly equal to half the angle between two pole corners, for smooth drum armatures.

The total number of ampere-turns required on field coils of dynamo will be the sum of all the ampere-turns required for the various parts of the circuit.

$$AT = at_g + at_a + at_{w.i.} + at_{c.i.} + at_r$$
$$= 14{,}295 + 82 + 3093 + 1490 + 2554$$
$$= \textbf{21,514 ampere-turns.}$$

(*d*) Calculation of Magnet Winding.

The shunt winding should be calculated for a temperature increase of about 15°C above the normal temperature. (If desired

the shunt coil may be calculated so as to give a higher voltage to the dynamo which can be decreased by a regulating resistance in series with the shunt coil. As this calculation is not required in order to show the electromagnetic theory of the dynamo it will not be discussed here. It requires a recalculation of the magnetic flux for the various parts of the magnetic circuit and a recalculation of the corresponding ampere-turns.)

1. Magnet Winding.

The mean length of one turn of wire on the field core is

$$l_{\mathrm{T}} = k_{17} \times d_{\mathrm{m}} = 3.66 \times 12\tfrac{1}{4}'' = 44.8''$$

where k_{17} = a constant, depending upon the size of the field core, giving the ratio of the length of a mean turn to the core diameter.

The specific length of magnet shunt wire in feet per ohm is given by the formula,

$$\lambda_{\mathrm{sh}} = \frac{L_{\mathrm{sh}}}{r_{\mathrm{sh}}}$$

$$= \frac{AT}{E} \times \frac{l_{\mathrm{T}}}{12} \times (1 + .004 \times \theta_{\mathrm{m}})$$

$$= \frac{21{,}514}{250} \times \frac{44.8}{12} \times (1 + .004 \times 15)$$

$$= 340.5 \text{ feet per ohm.}$$

No. 15 B & S has 315 feet per ohm.

No. 14 B & S has 397 feet per ohm.

Use about No. 14 B & S wire.

The height of the winding space is given by the formula

$$h_{\mathrm{m}} = \frac{l_{\mathrm{T}}}{\pi} - d_{\mathrm{m}} = \frac{44.8}{\pi} - 12.25 = 2 \text{ inches.}$$

The radiating surface of the magnet coils will be

$S_{\mathrm{M}} = (12.25 + 2 \times 2)\ \pi \times 2\ (18.375) = 1877$ square inches.

The energy absorbed in the magnet winding may be expressed by the formula,

$$P_{sh} = \frac{\theta_m}{75} \times S_M$$

$$= \frac{15}{75} \times 1877 = \textbf{375 watts.}$$

where P_{sh} = watts absorbed in field winding;

θ_m = rise of temperature in magnets, in degrees Centigrade;

S_M = radiating surface of magnet coils.

$$I_{sh} = \frac{P_{sh}}{E} \quad \text{or } I_{sh}\, E = P_{sh}.$$

Therefore the number of shunt turns may be found by

$$N_{sh} = \frac{A\,T}{I_{sh}} = \frac{A\,T \times E}{P_{sh}}$$

$$= \frac{21514 \times 250}{375} = \textbf{14,343 shunt turns.}$$

The length of the shunt winding is

$$L_{sh} = \frac{14{,}343 \times 44.8}{12} = \textbf{53,547 feet.}$$

The resistance of the shunt wire will be

$$r_{sh} = \frac{53{,}547}{340.5} = \textbf{157 ohms,} \text{ at } 15.5^\circ \text{ C.}$$

The warm resistance at 30.5° C is

$$r_{sh} = 157 \times (1 + .004 \times 15) = \textbf{166 ohms.}$$

The shunt current at full load is

$$I_{sh} = \frac{250}{166} = \textbf{1.5 amperes.}$$

If desired it is a simple matter to get the weight of the wire used.

331313

(e) Calculation of Efficiency.

The electrical efficiency of the dynamo is the ratio of the available energy to the available energy plus the energy lost due to armature resistance plus that due to field coil resistance.

$$\eta_e = \frac{P}{P + P_a + P_M}$$

$$= \frac{250 \times 200}{250 \times 200 + 1.06 \times 201.5^2 \times .0324 + 1.5^2 \times 166}$$

$$= .96 \text{ or } \mathbf{96\%} \textbf{ electrical efficiency.}$$

The commercial efficiency is the ratio of the output, to the sum of the output, wire loss in armature, wire loss in field, hysteresis loss, eddy current loss, and friction loss (which we will assume as 2,500 watts).

$$\eta_c = \frac{P}{P + P_a + P_M + P_h + P_e + P_o}$$

$$= \frac{50{,}000}{50{,}000 + 1{,}394 + 374 + 219 + 4 + 2{,}500}$$

$$= .917 \text{ or } \mathbf{91.7\%}\textbf{, commercial efficiency.}$$

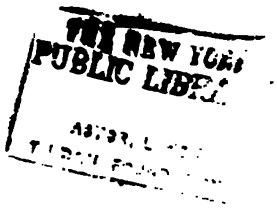
WIRE TABLE. PROPERTIES OF COPPER WIRE

Number B. & S. Gauge.	Diameter "d" in Mils. 1 Mil = .001 Inch.	Area in Circular Mils d^2.	Area in Thousandths of an Inch $d^2 \times .7854$.	Weight per Unit of Length. Specific Gravity, 8.89. Pounds per 1000 Feet.	Pounds per Mile.	Feet per Pound.	Ohms per Pound, Annealed.	Resistance in International Ohms at 68° F. According to Matthiessen's Standard of Resistivity. Ohms per 1000 Ft. Annealed.	Ohms per 1000 Ft. Hard-Drawn.	Ohms per Mile. Annealed.	Ohms per Mile. Hard-Drawn.	Feet per Ohm Annealed.	Tensile Sgth. in Pounds. Annealed.	Tensile Sgth. in Pounds. Hard-Drawn.	Elong. % in 1 Foot. Annealed.	Elong. % in 1 Foot. Hard-Drawn.	Safe Current in Amperes. Bright Wire Paneled.	Safe Current in Amperes. Black Wire in Free Air.	Turns per Lin. In. Cotton Covered.	Temperature Coefficients. Temp. in Deg. C.	Temperature Coefficients. Resistance per Mil-Foot; Ohms.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
0000	460.000	211600.00	.166190	640.5	3381.4	1.561	.00007639	.04893	.050036	.25835	.26419	20440	5650	9975	45.0	5.00	146.0	346.0	1.6	0	1.00000
000	409.642	167806.43	.131794	508.0	2682.2	1.969	.0001215	.06170	.063094	.32577	.33314	16210	4475	7900	45.0	5.00	127.0	292.0	1.6	1	1.00387
00	364.796	133076.66	.104518	402.8	2126.8	2.482	.0001931	.07780	.079558	.41079	.42007	12850	3550	6250	45.0	4.00	110.0	247.0	1.8	2	1.00776
0	324.861	105534.50	.082887	319.5	1686.9	3.130	.0003071	.09811	.10033	.51802	.52973	10900	2800	4950	45.0	4.00	95.0	209.0	2.8	3	1.01166
1	289.296	83692.67	.065732	253.3	1337.2	3.947	.0004883	.1237	.12649	.65314	.66790	8083	2225	3925	42.0	4.00	83.0	177.0	3.2	4	1.01558
2	257.626	66371.31	.052128	200.9	1060.6	4.977	.0007765	.1560	.15953	.82368	.84239	6410	1750	3125	39.0	3.00	72.0	148.0	3.4	5	1.01950
3	229.422	52634.37	.041339	159.3	841.09	6.276	.001235	.1967	.20114	1.0386	1.0621	5084	1400	2450	36.0	3.00	63.0	127.0	3.9	6	1.02343
4	204.307	41741.32	.032784	126.4	667.39	7.914	.001936	.2480	.25361	1.3094	1.3392	4031	1100	1950	33.0	2.50	55.0	108.0	4.5	7	1.02738
5	181.941	33102.37	.025999	100.2	529.06	9.980	.003122	.3128	.31987	1.6516	1.6889	3197	875	1550	30.5	2.50	48.0	91.0	5.0	8	1.03134
6	162.022	26251.37	.020618	79.46	419.55	12.58	.004963	.3944	.40332	2.0825	2.1295	2535	700	1225	28.0	2.00	42.0	78.0	5.6	9	1.03531
7	144.285	20818.35	.016351	63.02	332.75	15.87	.007892	.4973	.50854	2.6258	2.6850	2011	550	975	26.0	2.00	37.0	66.0	6.2	10	1.03929
8	128.490	16509.64	.012967	49.98	263.89	20.01	.01255	.6271	.64127	3.3111	3.3859	1595	425	775	24.0	1.75	32.0	56.0	7.0	11	1.04328
9	114.434	13092.75	.010283	39.63	209.24	25.23	.01995	.7908	.80876	4.1753	4.2769	1265	325	600	21.5	1.75	28.2	48.0	7.5	12	1.04728
10	101.897	10383.02	.0081548	31.43	165.95	31.82	.03173	.9972	1.0199	5.2637	5.3848	1003	275	475	19.0	1.50	24.9	41.0	8.5	13	1.05129
11	90.743	8234.11	.0064656	24.93	131.63	40.12	.03045	1.257	1.2854	6.6369	6.7869	795.3	200	375	17.5	1.50	21.9	35.0	9.7	14	1.05532
12	80.808	6529.95	.0051287	19.77	104.39	50.59	.08022	1.586	1.6218	8.3741	8.5633	630.7	175	300	16.0	1.25	19.3	30.0	11.2	15	1.05935
13	71.962	5178.48	.0040672	15.68	82.791	63.79	.1276	1.999	2.0443	10.555	10.794	500.1	125	225	14.5	1.25	17.0	25.8	12.0	16	1.06339
14	64.084	4106.72	.0032254	14.43	76.191	80.44	.2028	2.521	2.5779	13.311	13.612	396.6	100	200	13.0	1.25	15.0	22.2	13.0	17	1.06745
15	57.069	3256.78	.0025579	9.858	52.050	101.4	.3225	3.179	3.2508	16.785	17.165	314.5	80	150	12.0	1.25	13.3	19.1	15.3	18	1.07152
16	50.821	2582.74	.0020285	7.818	41.277	127.9	.5128	4.009	4.0996	21.168	21.646	249.4	60	125	11.0	1.25	11.8	16.5	16.7	19	1.07559
17	45.257	2048.29	.0016087	6.200	32.736	161.3	.8153	5.055	5.1692	26.691	27.294	197.8	50	90	10.0	1.25	10.4	14.2	17.7	20	1.07968
18	40.303	1624.30	.0012757	4.917	25.960	203.4	1.296	6.374	6.5180	33.653	34.416	156.9	40	70	9.0	1.25	9.2	12.3	19.5	21	1.08378
19	35.890	1288.13	.0010117	3.899	20.595	256.5	2.061	8.038	8.2196	42.441	43 400	124.4	30	60	8.0	1.20	8.2	10.7	22.7	22	1.08788
20	31.961	1022.53	.00080231	3.092	16.324	323.4	3.278	10.14	10.372	53.539	54.749	98.66	25	45	7.0	1.20	7.2	9.2	27.0	23	1.09200
21	26.463	810.12	.00063626	2.452	12.946	407.8	5.212	12.78	. . .	67.479	. . .	78.24	23	39	6.0	1.00	. .	. .	31.0	24	1.09612
22	25.346	642.45	.00050457	1.945	10.268	514.2	8.287	16.32	. . .	85.114	. . .	62.05	21	32	5.0	1.00	. .	. .	34.4	25	1.10026
23	22.572	509.49	.00040015	1.542	8.142	648.4	13.18	20.32	. . .	107.29	. . .	49.21	18	26	5.0	1.00	. .	. .	38.2	26	1.10440
24	20.101	404.04	.00031733	1.223	6.457	817.6	20.95	25.63	. . .	135.33	. . .	39.02	16	20	5.0	1.00	. .	. .	42.3	27	1.10856
25	17.901	320.42	.00025166	.9699	5.121	1031	33.32	32.31	. . .	170.59	. . .	30.95	12	16	5.0	1.00	. .	. .	47.0	28	1.11272
26	15.940	254.10	.00019958	.7692	4.061	1300	52.97	40.75	. . .	215.16	. . .	24.54	. .	. .	. .	. .	. .	. .	52.0	29	1.11689
27	14.196	201.52	.00015827	.6100	3.221	1639	84.23	51.35	. . .	271.29	. . .	19.46	. .	. .	. .	. .	. .	. .	57.0	30	1.12107
28	12.642	159.81	.00012551	.4837	2.554	2067	133.9	64.70	. . .	342.09	. . .	15.43	. .	. .	. .	. .	. .	. .	63.4	40	1.16332
29	11.258	126.74	.000099536	.3836	2.025	2607	213.0	81.70	. . .	431.37	. . .	12.24	. .	. .	. .	. .	. .	. .	70.1	50	1.20625
30	10.025	100.51	.000078936	.3042	1.606	3287	338.6	103.0	. . .	543.84	. . .	9.707	. .	. .	. .	. .	. .	. .	77.1	60	1.24965
31	8.928	79.70	.000062599	.2413	1.274	4145	538.4	129.9	. . .	685.87	. . .	7.698	. .	. .	. .	. .	. .	. .	84.6	70	1.29327
32	7.950	63.20	.000049643	.1913	1.010	5227	856.2	163.8	. . .	864.87	. . .	6.105	. .	. .	. .	. .	. .	. .	92.7	80	1.33681
33	7.080	50.13	.000039368	.1517	.801	6591	1361	206.6	. . .	1090.8	. . .	4.841	. .	. .	. .	. .	. .	. .	101.6	90	1.37995
34	6.305	39.75	.000031221	.1203	.635	8311	2165	260.5	. . .	1375.5	. . .	3.839	. .	. .	. .	. .	. .	. .	112.1	100	1.42231
35	5.615	31.52	.000024759	.09543	.504	10482	3441	328.4	. . .	1734.0	. . .	3.045	. .	. .	. .	. .	. .	. .	119.7	. .	. . .
36	5.000	25.00	.000019635	.07568	.400	13217	5473	414.2	. . .	2187.0	. . .	2.414	. .	. .	. .	. .	. .	. .	130.6	. .	. . .
37	4.453	19.83	.000015574	.06001	.317	16666	8702	522.2	. . .	2757.3	. . .	1.915	. .	. .	. .	. .	. .	. .	140.6	. .	. . .
38	3.965	15.72	.000012345	.04759	.251	21015	13870	658.5	. . .	3476.8	. . .	1.519	. .	. .	. .	. .	. .	. .	151.0	. .	. . .
39	3.531	12.46	.0000097923	.03774	.199	26500	22000	830.4	. . .	4384.5	. . .	1.204	. .	. .	. .	. .	. .	. .	163.4	. .	. . .
40	3.145	9.88	.0000077634	.02993	.158	33416	34980	1047.0	. . .	5528.2	. . .	.955	. .	. .	. .	. .	. .	. .	177.6	. .	. . .

WIRE TABLE. INSULATED WIRE.

Gauge of Wire.		Diameter of Wire (bare).		Single Cotton Insulation.				Double Cotton Insulation.			
B. W. G.	B. & S.	inch	mm	Thickness of insulation. Inch.	Ratio of bare diameter to thickness of insulation.	Weight of insulation per 100 lbs. of covered wire.	Weight of covered wire per lb. of bare wire, k_s.	Thickness of insulation. Inch.	Ratio of bare diameter to thickness of insulation.	Weight of insulation per 100 lbs. of covered wire.	Weight of covered wire per lb. of bare wire, k_s.
1	..	.300	7.62	..	..	..	..	.020	15	2.28	1.022
..	1	.289	7.34	..	..	..	..	.020	14.45	2.32	1.022
..	..	.284	7.21	..	..	..	..	.020	14.2	2.33	1 023
3	..	.259	6.58	..	..	..	..	.020	12.95	2.40	1.024
..	2	.258	6.55	..	..	..	..	.020	12.9	2.40	1.024
4	..	.238	6.04	..	..	..	..	.020	11.9	2.50	1.025
..	3	.229	5.82	..	..	..	..	.020	11.45	2.55	1.025
5	..	.220	5.59	..	..	..	..	.020	11	2.65	1.026
..	4	.204	5.18	.012	17	2.20	1.022	.020	10.2	2.85	1.028
6	..	.203	5.16	.012	16.9	2.20	1.022	.020	10.15	2.86	1.028
..	5	.182	4.62	.012	15.15	2.27	1 0227	.018	10.1	2,87	1.028
7	..	.180	4.57	.012	15	2.28	1.0228	.018	10	2.90	1.029
8	..	.165	4.19	.012	13.75	2.33	1 0233	.018	9 17	3.20	1.032
..	6	.162	4.12	.010	16 2	2 24	1 0224	.018	9	3.25	1.032
9	..	.148	3.76	.010	14.8	2.30	1 023	.016	9.25	3.15	1.031
..	7	.144	3 66	.010	14.4	2 32	1.0232	.016	9	3.25	1.032
10	..	.134	3.40	.010	13.4	2.36	1 0236	.016	8.4	3.55	1.035
..	8	.1285	3.27	.010	12 85	2.40	1.024	.016	8	3.75	1.037
11	..	.120	3 05	.010	12	2.50	1.025	.016	7.5	4.10	1 041
..	9	.1144	2.91	.010	11.4	2.55	1.0255	.016	7.1	4.35	1 043
12	..	.109	2.77	.010	10.9	2.66	1.0266	.016	6.8	4.60	1.046
..	10	.102	2.59	.010	10.2	2 85	1.0285	.016	5.4	5.00	1.05
13	..	.095	2.41	.010	9.5	3.10	1.031	.016	5.9	5.55	1.055
..	11	.091	2.31	.010	9.1	3.25	1.0325	.016	5.7	5.85	1.058
14	..	.083	2.11	.007	12	2.50	1.025	.016	5.2	6.60	1.066
..	12	.081	2.06	.007	11.6	2.54	1.0254	.016	5.1	6.80	1.068
15	13	.072	1.83	.007	10.3	2.80	1.028	.016	4.5	7.80	1.078
16	..	.065	1.65	.007	9.3	3.15	1.0315	.016	4.1	8.60	1.086
..	14	064	1.63	.007	9 1	3.25	1.0325	.016	4	8.80	1.088
17	..	.058	1.47	.007	8.3	3.60	1.036	.014	4 1	8.60	1.086
..	15	.057	1.45	.007	8.1	3.70	1.037	.014	4 1	8.60	1.086
..	16	.051	1.30	.007	7.3	4 20	1.042	.014	3.6	9 60	1.096
18	..	.049	1.25	.007	7	4.40	1 044	.014	3.5	9.80	1.098
..	17	.045	1.15	.005	9	3 25	1.0325	.012	3.75	9.30	1.093
19	..	.042	1.07	.005	8.4	3.55	1.0355	.012	3.5	9.80	1 098
..	18	.040	1.02	.005	8	3.75	1.0375	.012	3 33	10.10	1 101
..	19	036	0.91	.005	7.2	4.30	1.043	.005*	7.2	5 60	1.056
20	..	035	0 89	.005	7	4 40	1.044	.005*	7	6.00	1.06
21	20	032	0.81	.005	6.4	5.00	1.05	.005*	6.4	6.60	1.066
22	21	028	0 71	.005	5.6	6.00	1 06	.004*	7	6.00	1 06
23	22	025	0 64	.005	5	7.00	1.07	.004*	6.25	7.00	1 07
24	23	.022	0.56	.005	4.4	8.00	1 08	.004*	5.5	8.00	1 08
25	24	.020	0.51	.005	4	8.80	1.088	.004*	5	8 80	1 088
26	25	.018	0.46	.005	3.6	9.60	1.096	.004*	4.5	9.60	1 096
27	26	016	0.41	.005	3.2	10.40	1.104	.004*	4	10.40	1.104
28	27	.014	0.36	.005	2.8	11.25	1.1125	.004*	3.5	11.25	1.112
29	28	.013	0.33	.005	2 6	11.65	1.1165	.004*	3.25	11.65	1.116
30	..	.012	0.31	.005	2.4	12.05	1.1205	.004*	3	12.05	1.120
..	29	011	0,28	.005	2.2	12.45	1.1245	.004*	2 75	12 45	1.124

* Double silk : 1 mil of silk insulation taken equal in weight to 1.25 mil of cotton covering.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2700 K. W. CONTINUOUS CURRENT RAILWAY GENERATOR.
Built by General Electric Company for Boston Elevated Railway.

TYPES OF DYNAMO-ELECTRIC MACHINERY: (Direct Current.)

We will now consider the general characteristics of the various types and the methods and materials of construction of dynamo-electric machinery.

Within the last ten years dynamo-electric machines have been very extensively introduced, and great improvements have been made in their construction. In former years the generator was often poorly built; its mechanical faults considerably decreased its usefulness, and led to frequent repairs. High grade generators such as are now manufactured are much stronger mechanically, simpler in construction, more reliable in operation and more durable. An important advance is the considerable reduction in electrical and frictional losses. This reduction gives both increased efficiency, and less danger of overheating.

In recent years the special design of electric machinery for particular classes of work has become a highly important feature of electrical engineering, owing to the many novel applications for which this class of machinery is now used.

The following pages contain numerous modern types of electric machinery, examples being chosen from actual practice to illustrate the most modern usage.

CONSTANT CURRENT AND CONSTANT POTENTIAL GENERATORS.

Direct current generators may be divided into two types, those furnishing a variable current at a fixed voltage or potential; and those giving a constant current, the potential in this case being made to vary with the requirements of the load.

By far the greater number of the modern generators are of the constant potential type. These are used in practically all

power and incandescent lighting circuits. The constant current type is devoted mostly to arc lighting. It should be noted however that in many instances arc lights are now run from the constant potential system.

METHODS OF DRIVING GENERATORS.

We may distinguish the following principal methods of driving generators. These methods are used according to local requirements.

Direct Steam or Gas Engine Driven — (Including the "Engine Type");

Indirect Steam or Gas Engine Driven — (Belt, Wire and Rope Driving);

Water-Turbine Driven;

Steam-Turbine Driven.

Direct Steam or Gas Engine Driven Generators. Generators of large size used in connection with steam or gas engines are now commonly driven directly from the engine shaft. That is to say, the engine shaft is extended out to one side of the engine, and is provided with an extra bearing. Onto the extended shaft the revolving part (usually the armature) of the generator is keyed.* Often the shaft is slightly tapered, and the armature is driven onto it by screw jacks, under great pressure. Some manufacturers bolt the revolving part of the generator directly to the fly-wheel.

A generator having its revolving part carried by the engine shaft is usually spoken of as an "**engine type**" generator. Such a generator has no shaft of its own and no bearings, both shaft and bearings being provided by the engine maker. Other direct-driven generators have both shaft and bearings, the shaft carrying a coupling flange which is bolted directly to a similar flange on the engine shaft. A fly-wheel is usually provided, since

*Note. — In direct current generators it is in nearly all cases the armature that revolves. In some alternating current generators the armature revolves (inside of a stationary field), while in other types of this class the armature is stationary, and the field magnets are made to revolve Whichever it is that revolves, armature or field, it is evident that the essential process, the "cutting of lines of force," is the same.

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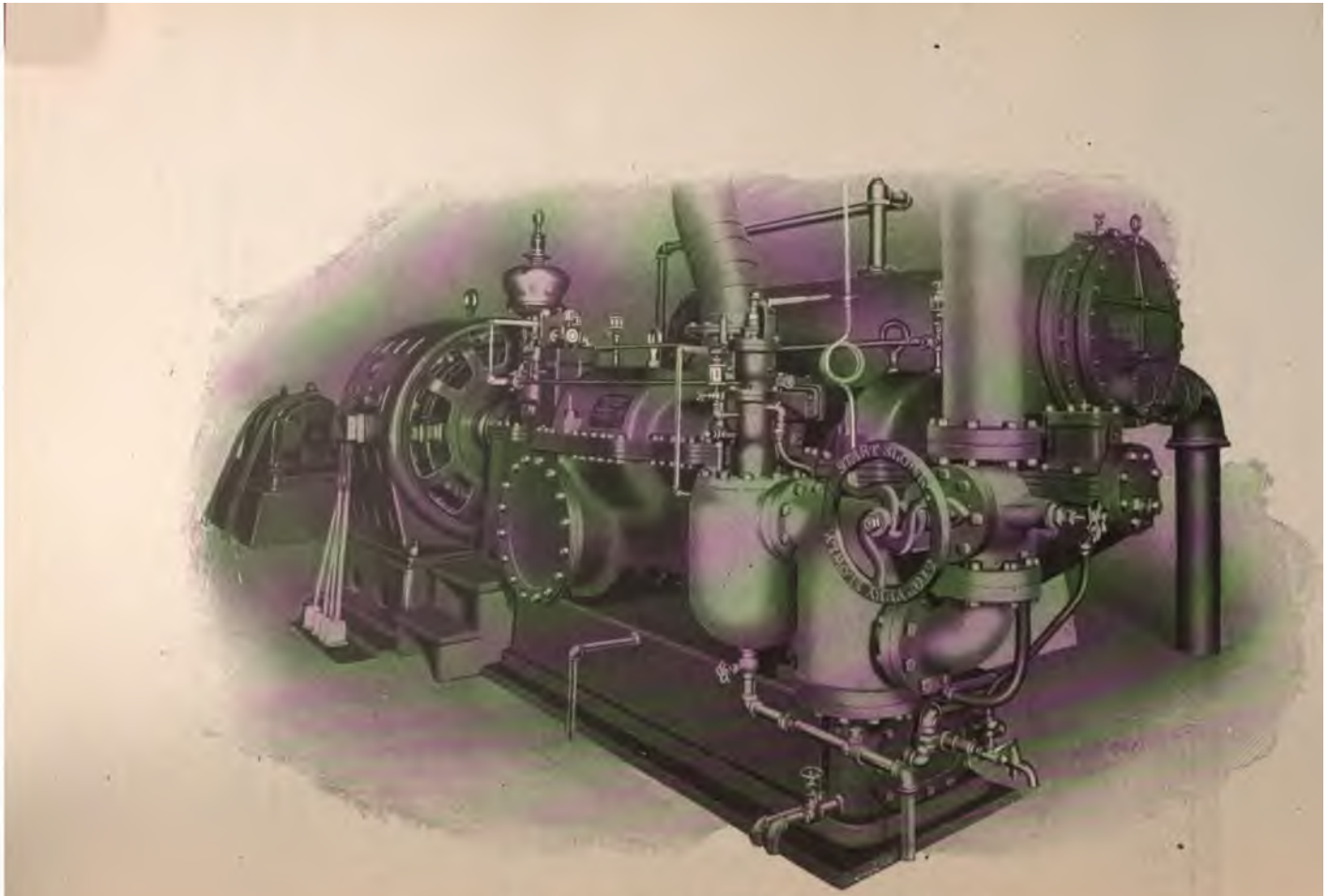


400-Kw. TURBINE GENERATOR UNIT INSTALLED.
With Surface Condenser Above Floor.

Westinghouse Machine Company

the rotating part of the generator is not sufficiently massive to give steadiness of running.

An important advantage possessed by the direct connected generator is the small floor space required. In belt driving it is customary to place the generator at a considerable distance from the engine, and the intermediate floor space is usually not available for other purposes.

Indirect Steam or Gas Engine Driven Generators. In the indirect methods of driving, (including the belt, wire and rope systems), generators are run at a great variety of speeds by various kinds of belt, rope and wire driving gear. Small generators are ordinarily driven by one or the other of these indirect methods, several generators being commonly connected to one engine. Generators of from 10 to 50 K. W. capacity usually carry a small metal, wooden or composition pulley which overhangs the main bearings. If the generator is of larger size a third or "outboard" bearing is provided to relieve the bending strain caused by the belt pull.

Water-Turbine Driven Generators. The recent development of water-power in different parts of the country has given rise to the third type or water-turbine driven generators. These machines are of a very different design from those driven by steam engines. Engine driven generators ordinarily have a horizontal shaft, whereas the turbine, being usually at the bottom of a vertical tunnel, requires a vertical shaft, onto which the revolving part of the generator is directly bolted or keyed. The generator is thus, as it were, turned on its side, and an entirely different system of stresses has to be provided for. Such generators are usually of large size, ranging from 100 to 3000 K. W. Even larger sizes are occasionally constructed. This fact is due to the use of water wheels or turbines of great size, the division of the water-power among a number of small turbines being unsatisfactory. Such generators are almost invariably direct driven from the turbine shaft.

Steam-Turbine Driven Generators. The next main division of generator-driving systems comprises the steam-turbine driven generator. This system is comparatively new, having been developed within the last few years in England and America,

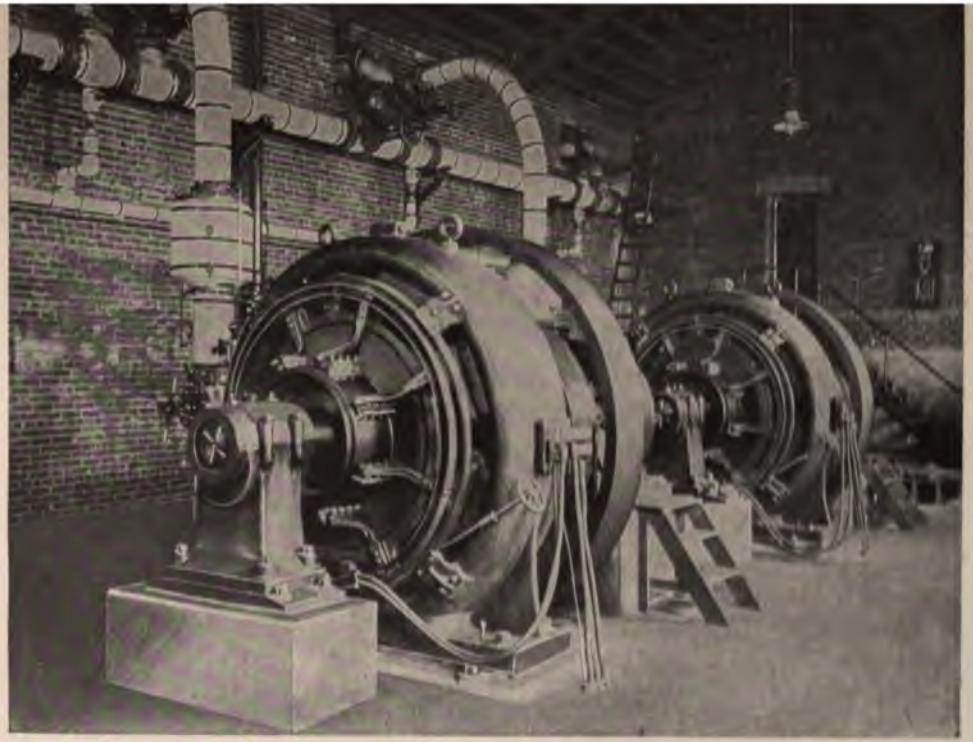
mainly since the invention of the Parsons Steam Turbine. Generators so driven, show still further variation from the usual types. The steam-turbine rotates at very high speeds and it is not practicable to use belting with it. The system of direct driving is therefore employed, the revolving part of the generator being bolted or keyed to the shaft of the turbine. Owing to the enormous speed at which the turbine revolves (sometimes several thousand revolutions per minute) the design of the generator is greatly modified. The voltage of a generator depends upon three factors: the speed of revolution, the magnetic flux, and the number of turns in series on the armature. The speed in this particular case being so excessive, the armature is made relatively small and the field is of the simple bipolar type.

STEAM AND GAS ENGINE DRIVEN GENERATORS.

Direct- and Belt-Driven Generators. It is impossible to fix any limit between the sizes of generators which are belt-driven and those which are direct driven. As a general thing, generators of less than 200 K. W. capacity are driven by belting, while nearly all of 500 K. W. and over are driven direct from the engine shaft. Between these limits of 200 and 500 K. W., both belt and direct-driven types are extensively in use. As a general rule however designers now prefer the direct-driven types for all except the very smallest sizes.

It is also impossible to fix any general limits of generator speed. The standard types of stationary engines of large sizes are, generally speaking, slow-speed. From 275 revolutions per minute, in the moderate size engines, the speed decreases as the size of the engine increases. Seventy-five or 80 R. P. M. is the usual speed of the large central station engines.

Since the speed is fixed by the requirements of steam engine design, the direct-driven generator is designed to meet these conditions. Such machines have from 6 to 28 poles, the number of poles increasing with the size of the generator. The revolving armature is made quite narrow, but of great radial depth, the diameter in the large sizes being sometimes 30 feet. Such an armature differs very strikingly from the compact armatures of



DIRECT-CONNECTED GENERATORS
Operating the Largest Woodworking Plant in the United States.
Triumph Electric Company.

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small diameter used in the older belt-driven, high-speed generators.

The change from belt-driven to direct-driven generators has been very gradual. In 1893 several of the larger companies had constructed direct-driven generators of large size, and this date may be fixed as about the beginning of the present era of direct-driven generators.

Advantages of Direct-Driven Generator. In all applications of very large generators, where it is possible to do so, it is better to install one of the direct-driven types, as even the best system of belting is unsatisfactory for transmitting great power. Moreover, the introduction of shafting, counter shafting and belt, rope or wire driving, causes losses by friction, which are sometimes excessive when large generators have to be driven. These losses are avoided by the use of direct-driven generators. Also high-speed belt-driven generators necessarily have armatures of small diameter, since larger diameters would not be suitable for driving at very high rates of revolution. Armatures of small diameter, however, in which the windings are compactly placed, are very imperfectly ventilated, and often give a great deal of trouble by overheating. Faulty insulation and poor efficiency are the result.

The direct-driven generator, on the other hand, operating at slow speed, has an armature of much larger diameter, so that the windings are spread out over a much greater surface. This gives facilities for practically perfect ventilation. As a rule the direct-driven generators keep cool much better than the belt-driven type, and will stand far greater overloads.

Another point of great importance in determining the type of generator to be installed is the ease with which repairs can be made.

In the older belt-driven armatures the coils are compactly wound and bound about by insulation; the burning out of a coil usually makes it necessary to take the armature to pieces for repairs. In the modern direct-driven armature the coils are spread out over a large surface, and are well separated from each other. Repairs are, therefore, made with the utmost facility. Any individual coil may be separately removed. Such repairs,

owing to the perfect ventilation of the armature, are rarely needed. An armature of this type will take severe overloads without permanent injury. Ordinarily however such machines are more expensive to install than the belt-driven types. There are indeed some cases in which the belt-driven generator is to be preferred — particularly in the smaller sizes, on account of the smaller first cost, and the ease with which it may be adapted to engines already in use.

The leading manufacturers are now making belt-driven moderate-speed generators (500 R. P. M. for example), in which some of the important features of the direct-driven type are preserved. These machines have fairly large, well ventilated armatures, and will take quite heavy overloads. They are rapidly supplanting the old generators with small, close-wound and unventilated armatures. In general, therefore, it may be said that present practice (1903) is, in large power plants, to use direct-driven slow-speed generators, and in smaller installations to use belt-driven generators. These belt-driven generators, as far as possible, embody the best features of the direct-driven type.

It should however be noted that the steam-turbine driven generator, now slowly coming into use, completely reverses the usual tendency toward slow-speed armatures of large diameters. The steam-turbine speeds range from 1200 to 3500 R. P. M., and the use of direct current generators, rotating at such speeds, is open to question. Commutation would be very difficult, and ventilation of complicated armature windings would be almost impossible. Generators driven by the steam-turbine are, as a rule, of the alternating current type and do not therefore come under this part of the subject. Alternating current machines are considered separately.

WATER-DRIVEN GENERATORS.

Reference has already been made to the general considerations governing water-driven generators. Such generators usually belong to the alternating current class, although the direct current system is entirely practicable. The reason for generally using the alternating current system in this connection is as follows. As a rule, the water-power is not located near manufactur-

ing centers, and so the electric supply has to be sent out over considerable distances. Moreover, the alternating current has important advantages whenever electric power has to be conveyed over a long distance. For these reasons the use of the direct current system is limited mostly to cases where the current is trans-

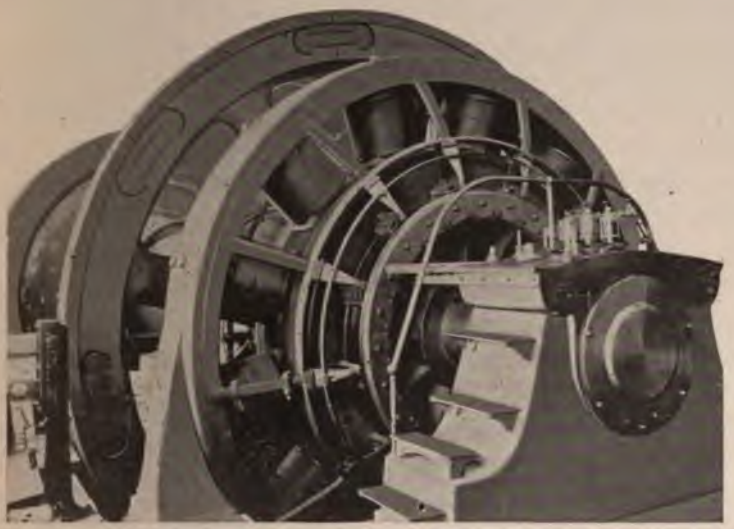

Fig. 1. General Electric Company's Direct-Connected Railway Generator, 550 K. W.

mitted over comparatively short distances. It is not necessary at this point to enter exhaustively into the subject of the relative advantages of the two systems. Each one has its field, and for the transmission of power over long distances the alternating current is necessary, while for other purposes, such as, for instance, the charging of storage batteries and electrolytic work, it is necessary to have a direct current.

REPRESENTATIVE DIRECT-DRIVEN GENERATORS.

General Electric Co.'s Railway Generator. Figure 1 shows the General Electric Company's direct connected "railway" generator. Such machines represent a high type of electrical

efficiency and mechanical soundness. They range in size from 2400 K. W. (3200 H. P.), having 28 poles and running at 75 R. P. M, down to 100 K. W., running at 275 R. P. M., and having 6 poles. The yoke of the field magnets, (seen in the illustration as the outside circular frame surrounding the coils), is of cast iron, of very massive design. The upper and lower halves of this cast-iron ring or yoke are cast separately, and are fastened together by bolts. This yoke carries the poles of the field, which are solid steel castings, accurately fitted and bolted to the inner face of the yoke. The bolt-heads are seen in the illustration. These poles are keyed in in such a way that they may be slipped out sideways, one at a time, in case of accident. These steel poles are, in the larger machines, made with laminated polar faces.* Each field-coil is separately wound and slipped into position upon the pole.

The armature windings and core are built up upon the rim of a strong central spider, shown in Figs. 3 and 4. This spider is so designed that it serves furthermore as a powerful fan, keeping a constant air blast passing through the armature windings. This is a feature of great importance in securing cool running. The armature core itself is laminated, the stampings of iron being put into position in such a way as to leave numerous radial air passages through the whole mass of the core. By means of these the blasts of air, coming from the arms or blades in the spider, pass

*All high-grade generators and motors now have laminated armature cores, and many of them have laminated field poles, though the field magnets themselves are usually made with solid cast-steel cores. A "laminated" core is made up of a great number of thin sheets of soft iron or steel pressed solidly together, making what is practically a solid mass of metal. It was found in the use of solid iron cores that eddy currents (see section on Direct Current Dynamos) were formed which reduced the efficiency of the machine. The soft-iron sheets, however, being magnetically insulated from each other (sometimes by a thin coating of japan, or by a thin film of rust), effectually prevent eddy currents.

Pole pieces in some machines are laminated for the same reason. By cutting away every alternate sheet of metal at the horns of the pole pieces it is possible to give the magnetic field just the degree of density that is best for the smooth running of the machine. This is done in the Westinghouse machines, and other makers produce somewhat similar effects by cast-steel pole pieces of special design.

through the armature windings. Slots are also provided upon the face of the core to receive the conductors.

The armature coils are bent into shape upon forms or patterns made of the exact shape that the coil will have upon the armature. After being bent into shape the coils are wrapped with insulation and fastened into the slots upon the armature by means of little insulating wedges or keys. A single coil is shown in Figure 2.

These wedges generally do away with binding wires, which were often found to interfere with the armature insulation and ventilation. A great advantage of this method is that a single

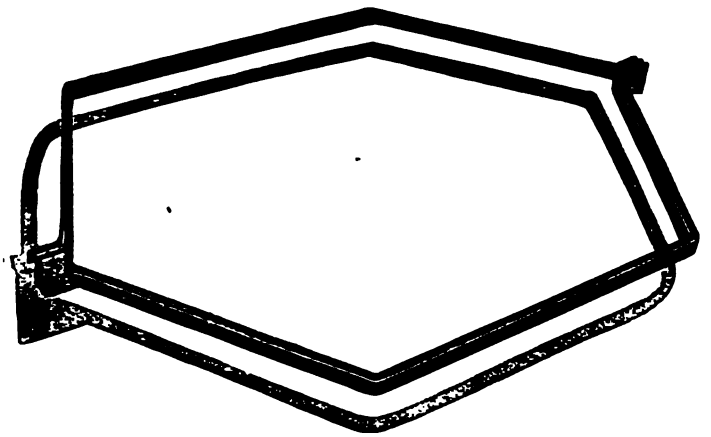

Fig. 2. Armature Coil for General Electric Generator.

coil or part of a coil may be removed from the armature separately.

It will be remembered that in multipolar machines the same potential exists or should exist at several points around the circumference of the armature, owing to the simultaneous action of the different poles. In the railway generator, as in other advanced types, such points of nearly equal potential are connected together by massive conductors arranged along one of the end faces of the armature. By this method any slight irregularities of adjustment (which would otherwise cause an unequal distribution of current around the armature) are compensated. These conductors are known as equalizer rings and are an important feature of modern machines of this class.

Commutators and brush holders are of massive design, allowing large surfaces of contact and ample chance for ventilation.

The commutator brushes are carried on a ring as seen in Figure 5. This ring is moved by means of the rod and hand-wheel seen at the left of the figure. The complete machine, together with the engine shaft, bearings and fly-wheel, is seen in Figure 1.

These machines are compound-wound and the voltage varies from 525 at no load to 575 at full load. By shunting the series

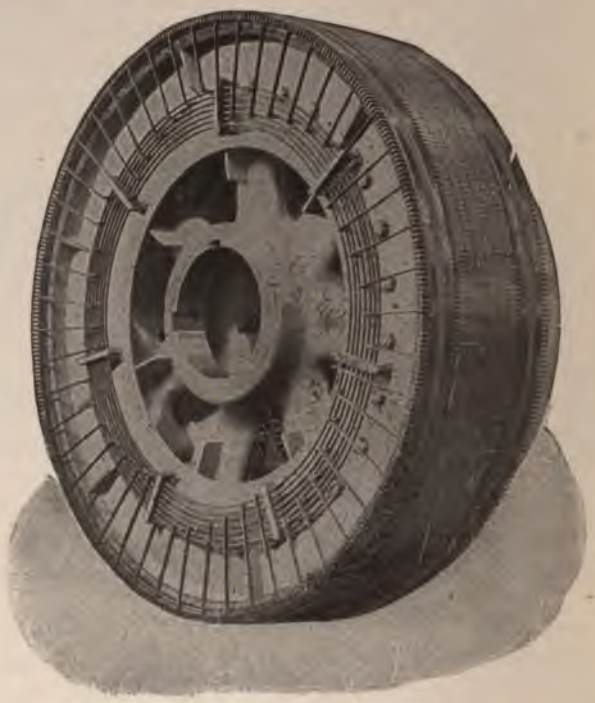

Fig. 3. Rear View of General Electric Armature Showing Equalizer Rings.

field, this over-compounding may be reduced as desired. Two or more of these generators will work perfectly in parallel.

The General Electric Company makes very similar machines for lighting and general power service. The essential difference between these and the railway generator is the voltage. The lighting and power generators are usually wound for from 125 to 300 volts, while railway generators usually give from 500 to 550 volts. The danger of injury to the armature through short cir-

cuits is practically removed by the use of massive armature conductors made of bar copper.

All these armatures are constructed on what is known as the "iron-clad" principle; that is to say, the conductors, as we have seen, are not wound upon the surface of the armature core, but are imbedded quite deeply in slots which are cut through the sheet metal core. In this way the soft copper conductors with their

Fig. 4. Front View of Armature and Commutator.

insulating material are protected from all injury by the projecting portions of the iron core.

Similar machines are made by the **Crocker-Wheeler Company.** Fig 6 is an excellent representation of this company's engine-type generator.

In the Crocker-Wheeler machines the magnet frame is a cast-iron ring, stiffened by flanges like a girder, the upper and lower

halves are cast separately and are accurately fitted together and held by bolts. The upper half may be lifted off from the machine if repairs are necessary.

In all these direct-driven generators the lower part of the

Fig. 5. Field and Brush Holders of a General Electric Generator.

magnet frame carries iron feet which are bolted down to a supporting base.

Westinghouse Engine-Type Generator. Fig. 7 shows a Westinghouse direct current engine-type generator. It has nei-

ther shaft nor bearings, both of these being supplied with the engine. This particular machine is wound for 125 volts. The field frame is of soft steel and is cast in two parts. These two parts are divided from each other in a vertical plane; that is, the right and left hand sides of the field may be unbolted and drawn apart on slide rails provided for this purpose. The poles are cast welded* into the yoke or frame of the magnets; and the field-coils, separately wound, are slipped onto these poles,

Fig. 6. Crocker-Wheeler Engine-Type Generator.

where they are bolted into position. The armature core, carried by a cast iron spider, is built up of thin discs of carefully annealed steel. Air ducts are left through the core as in the types already discussed, and ventilation is practically perfect. Fig. 8 shows a 200 K.W. Westinghouse generator connected to a Westinghouse steam engine.

The armature windings are usually of heavy bar copper set

*See Page 35.

into grooves in the surface of the armature core. Fig. 9 shows this construction very clearly. The commutator, built up of hard rolled copper, insulated with specially prepared mica of great hardness, has excellent ventilation, and provides a surface that wears evenly.

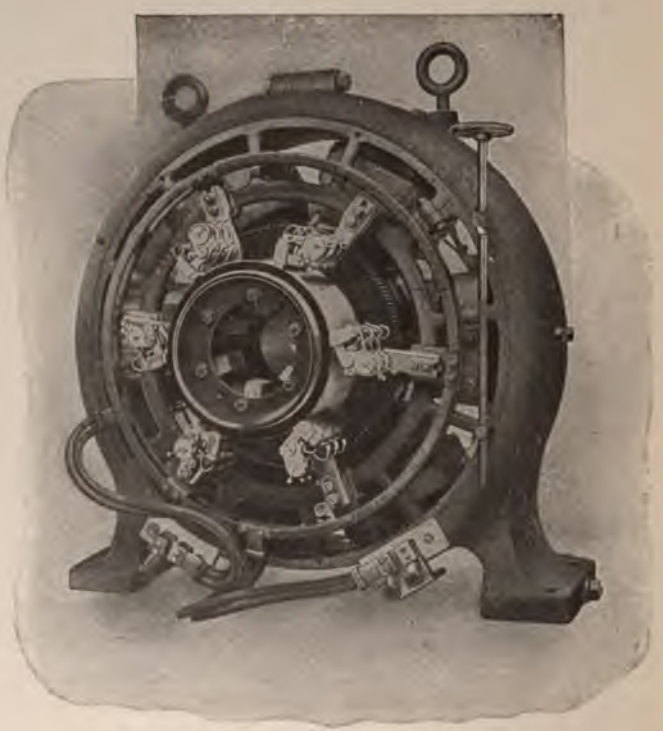

Fig. 7. Westinghouse Engine-Type Generator.

Years ago many inferior makes of machines carried commutators of soft copper insulated with soft material. Such commutators wore rapidly into irregular grooves, which made good commutation impossible. High-class machines are now built with practically indestructible commutators. This is one of the most vital features of direct current work, and careful examination of the commutator is necessary in making a choice of machines. Fig. 10 shows the complete armature of a Westinghouse 800 K. W.

engine-type generator, and Fig. 11 shows such a machine assembled upon the engine shaft, together with the enormous fly-wheel. This fly-wheel is necessary for smooth running at slow speeds, such as are common in direct-driven machines.

The Westinghouse direct-connected railway generator is shown in Fig. 12. Bearings are provided by the engine builder, the armature of the generator being mounted upon the shaft of the engine. The field castings are divided vertically, and the two halves are bolted together so firmly as to constitute a good magnetic circuit. By this construction it is rendered easy to inspect the armature at any time by unbolting the field and moving it sideways. This arrangement is particularly valuable in engine rooms where there is but little head room, or where overhead cranes for handling heavy castings are not available. Machines of similar design are however constructed by the Westinghouse E. & M. Co., having a field divided horizontally, the top half being removable by means of a suitable crane. The bolts for securing together the two halves of the field are in this case at the sides of the field.

Railway generators are usually overcompounded, a rise of 10% in the voltage being allowed for from no load to full load. The compound windings for one of the pole pieces are shown in Fig. 13. Shunt and series coils are mounted upon a light metallic skeleton frame, which is slipped on over the pole piece. The coils are well ventilated and easily removable.

Fig. 14 shows the core for the armature of a railway generator. This core, mounted upon a cast-iron spider, as shown, is slotted to receive the windings, rows of ventilating ducts being left around the circumference. Fig. 15 shows the complete armature and commutator, the temporary shaft seen in Fig. 14 being omitted in Fig. 15. In the latter figure the armature is seen resting on the floor, the delicate insulated windings being protected from injury by their position, since they are sunk beneath the surface of the core.

Fig. 16 shows a group of these machines as installed at the United Traction Company's plant at Allegheny, Pa. These machines are each of 500 K. W. capacity, and uniform speed is secured by means of the enormously heavy fly-wheels shown.

They are driven by horizontal engines, which are not clearly shown in the illustration.

The **Lundell** Split-Pole Generator, manufactured by the Sprague Electric Co., is shown in Fig. 17. In this generator

Fig. 8. Westinghouse Engine and Generator.

the pole pieces are divided into two approximately equal parts; one of these parts has a large extension along the face of the pole, and the other part has a much smaller extension. The result is that a small exciting current will fully magnetize one

part, but will not fully magnetize the other. When this current is increased the magnetism of the part having a large polar extension is slightly increased, while the part with the small extension has its magnetism more rapidly increased. This results in diminishing the distortion of the field, and consequently the point of commutation remains practically fixed. It is claimed by the manufacturers that this device does away with the necessity of shifting the brushes, the brushes being once set properly.

The yoke is circular, and consists of two steel castings. The pole pieces are bolted to the yoke. The armature is of large diameter, and is of the iron-clad type. The core is laminated and

Fig. 9. Armature of Westinghouse Generator.

built up of soft annealed sheet-steel punchings, thoroughly japanned, and secured to a spider, which is keyed to the shaft. The commutator is unusually massive, giving abundant capacity, without excessive heating. The commutator bars are of hard drawn copper, carefully insulated from each other with the best grade of mica. The completed commutator is solid, accurately turned and smooth running. The split-pole type of generator is made in sizes ranging from 25 K. W. to 1000 K. W.

The Triumph Electric Company manufactures multipolar generators of both slow and moderate speed types, as shown by the accompanying illustrations. Fig. 18 shows the Triumph

multipolar direct current generator direct connected to a Corliss engine. Fig. 19 shows the Triumph generator as adapted to use on shipboard, mounted upon the bedplate of a vertical engine. Fig. 20 shows a larger machine also mounted upon the shaft of a vertical engine.

Fig. 20 shows a larger machine mounted upon the shaft of a horizontal engine.

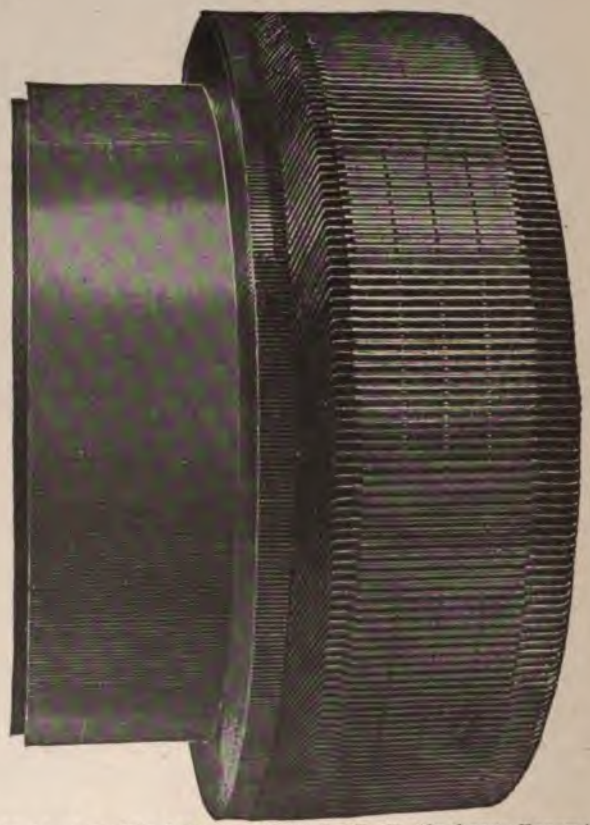

Fig. 10. Complete Armature of 800 K. W. Westinghouse Generator.

tion. Fig. 22 shows a complete Triumph armature. No shaft is provided, the armature being designed for direct mounting upon the shaft of an engine.

Fig. 23 shows the **Fort Wayne Electrical Works'** 400 K. W. direct-driven multipolar generator for connection to a horizontal

engine. This machine, together with others manufactured by the Fort Wayne Works, comprises what is known as the "Wood" System.

The direct-driven generators range from 15 to 800 K. W.; the smaller sizes have 6 poles and the largest size 16. These machines are designed with special reference to quiet, steady running, a feature which makes them available for use in hotels and office buildings.

The cores of the field magnet poles are of fine laminated iron cast into the body of the frame by a special construction. The magnetic circuit is undoubtedly good.

The armature is of the "iron-clad" type, and is wound with coils formed separately on patterns. The core is of laminated sheet iron. Light binding wires are applied to the armature coils, but the core is made with ventilating ducts, and a constant circulation of air is maintained through the armature windings.

The illustration shows large commutator surface and good brush area. The brushes are shifted by turning a small hand-wheel on a long screw threaded through a lug on the brush lattice These machines run at the comparatively low speeds of 375 to 80 R. P. M.

A representative type of direct-driven generators, manufactured by the **Bullock Electric Mfg. Co.**, is illustrated by Fig. 24. This shows the 800 K. W. type "I" direct current Bullock generator, direct connected to a cross-compound Corliss engine. Like other direct-driven generators, this machine operates at the very low speed of from 85 to 90 R. P. M. These machines are designed to meet the requirements of different engines. It will be seen that the field yoke is divided horizontally, being cast in two semicircular sections, which are bolted together midway of the height of the generator. The pole pieces, of laminated soft steel, are so formed as to produce a uniform magnetic flux across the air-gap. In the Bullock machines the poles are bolted to the yoke, the nuts being concealed in the interior of the pole pieces.

These generators are usually overcompounded for a rise in potential of 3% from no load to full load, but this compounding may be varied as required.

The armature core is carried upon a massive spider, shown in Fig. 25. The core itself is built up of thin sheet steel of high magnetic permeability. Ample ventilating ducts are provided as usual. Interchangeable armature windings of copper-bar or wire

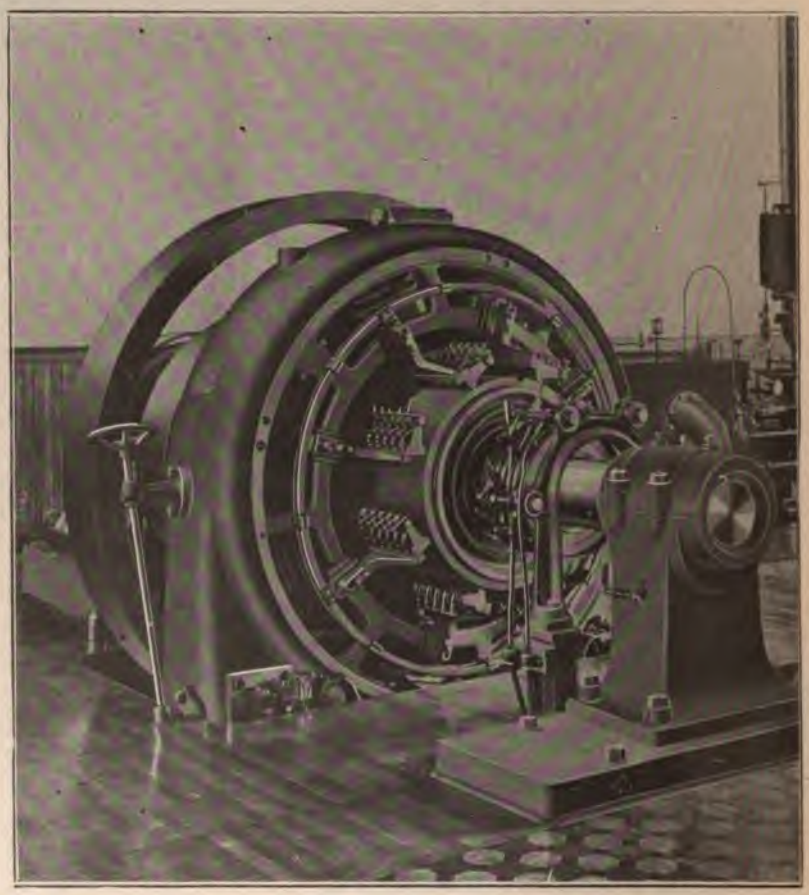

Fig. 11. Complete Westinghouse Generator, Mounted.

are used. Each conductor is wound with tape, then the conductors for a coil are grouped together and taped as a whole. After this the coil is dipped into an insulating compound. It is then still further insulated with rope paper, mica, and bond

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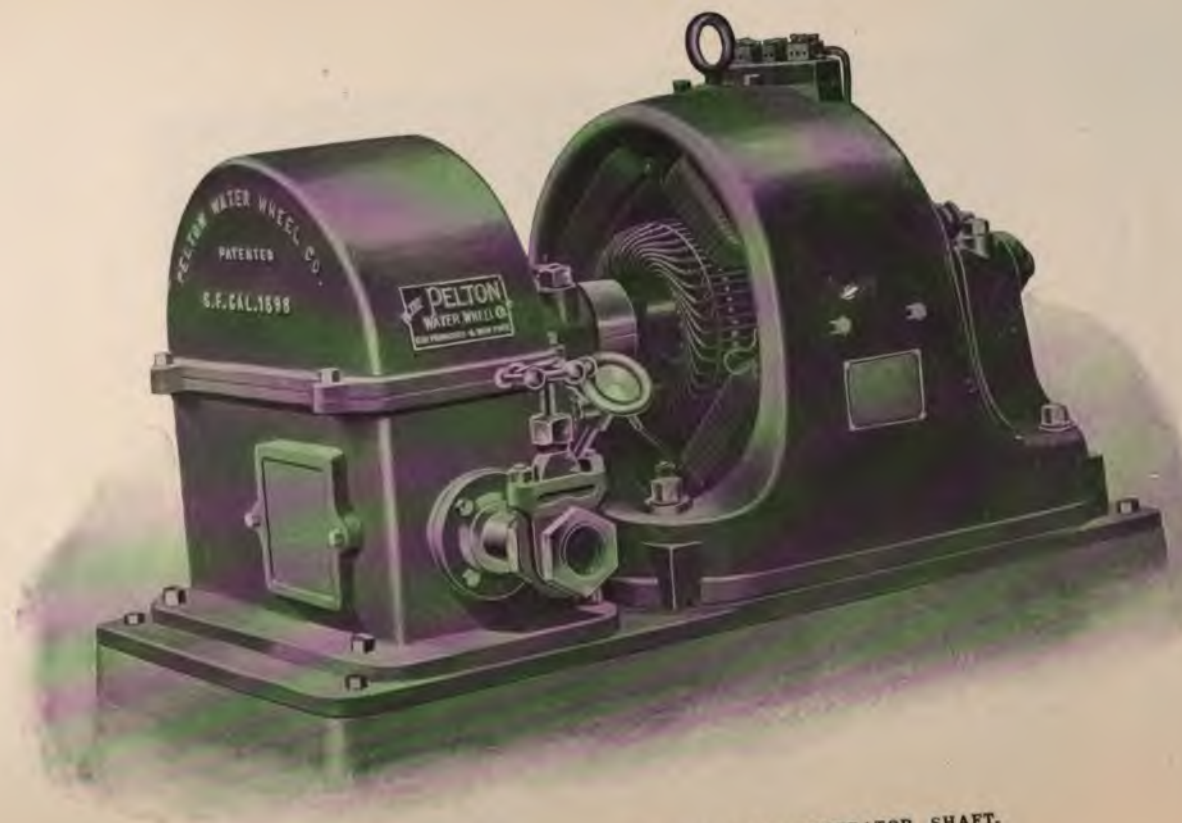


WATER MOTOR MOUNTED ON OVERHANG OF GENERATOR SHAFT.

Pelton Water Wheel Company.

paper, and is then armored with red fibre (or at least so much of the coil as is to be in contact with the armature slot). These coils are then baked at about 350° F. under pressure, this process removing all moisture. Insulation thus built up is of a very high grade, and the coils when placed upon the armature require no further insulation. Coils are held in position by wedges of hard wood, which are driven into notches in the armature slots. No band or binding wires are used. Fig. 26 shows the completed armature for a 76 K. W. Bullock generator. Fig. 27 shows the 800 K. W. Bullock generator disconnected from the engine.

At the top of Fig. 27 is shown a small wheel carried by the yoke of the machine. Two similar wheels are also carried by the frame of the machine, but are hidden by the base plate. These wheels support the large ring which carries the brush-holder mechanism. By means of this device the position of the brushes is adjusted through a handwheel, seen at the right of the figure.

Fig. 28 shows a 15 K. W. Bullock generator direct connected to a gas engine. Between the gas engine and the generator is seen a flexible coupling, carried within the body of the fly-wheel. Steadiness of running, ordinarily so difficult to obtain with gas engines, is insured by the use of a compound gas engine, by fly-wheels of massive construction, and by the mass of the armature.

Fig. 29 shows the efficiency curve for the 200 K. W. Bullock generator. The figures given at the base of the diagram show quarter, half, three-quarter and full loads and overloads. Efficiency is indicated in percentage, at the left of the diagram. The machine possesses high efficiency at full load, and the efficiency does not appreciably decrease until the load has fallen to one-half of the full load of the machine. It will, furthermore, be noticed that even at less than one-quarter load the efficiency is still very satisfactory.

Nearly all of the modern direct-driven generators show this peculiarity in the efficiency curve; namely, the efficiency remains practically constant over a very wide range of loads. In a small machine which is to be run constantly at its full output, this

characteristic of the efficiency curve is not necessary. But in a large machine which is to run for a great part of the time at small loads, it is of the utmost importance that the curve shall show high efficiency, even down to one-eighth of the full output.

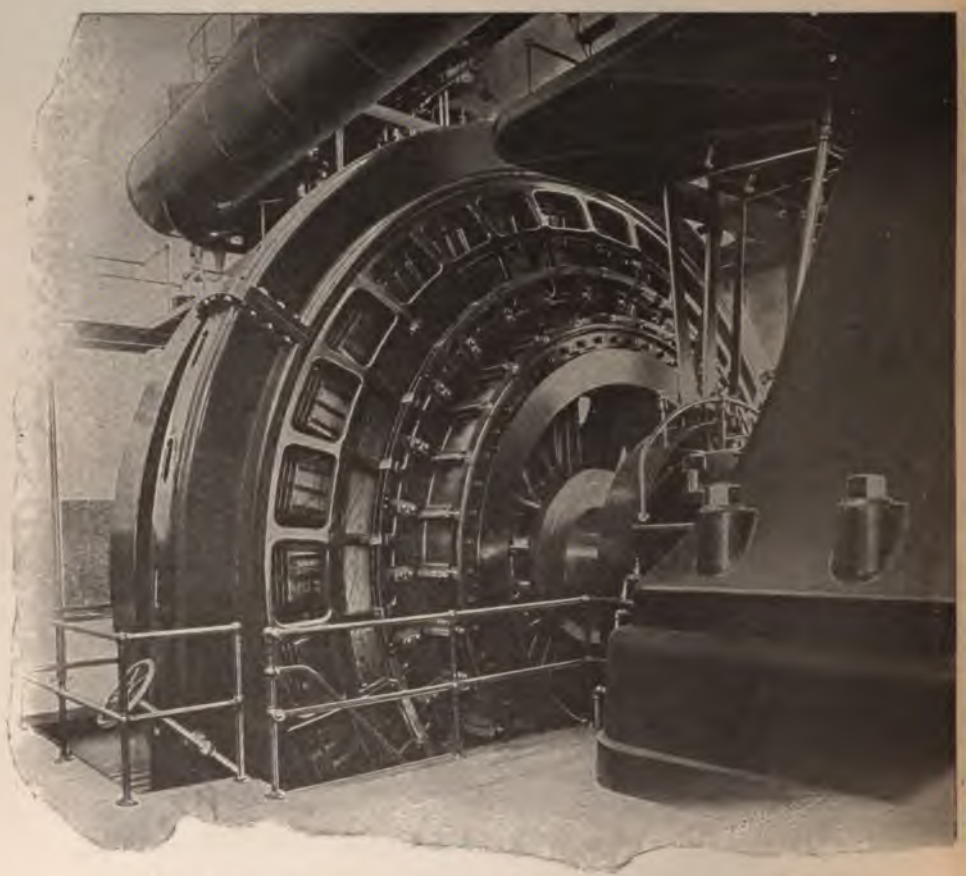


Fig. 12. 2500 K. W. Direct-Current Engine Type Railway Generator.

One of the most notable of recent types of electric machinery is the direct-driven lighting and power generator for use on ship-board. Fig. 30 shows a Bullock generator, direct connected to a Forbes vertical steam engine for marine use. In such machinery it is important to reduce the weight as much as is consistent with

safety, and the least possible space must be taken up by the engine and generator. At the same time, it is important that the machinery shall be of the greatest possible durability, as repairs can be made at sea only with great difficulty. The marine generator shows the leading characteristics of the high-grade machines hitherto described, the principal difference being the greater compactness of marine design. The voltage is usually fixed at 110, and the speed ranges from 800 to 400 R. P. M., this latter speed being that of the 22 K. W. size.

Fig. 31 shows the C & C 6-pole engine-type generator. The C & C Company makes machines of this type in standard

Fig. 13. Westinghouse Compound Field Coil.

sizes of from 25 to 125 K. W., running at speeds of from 325 to 250 R. P. M. The smallest size has 4 poles, and the 125 K. W. size has 8 poles. These generators are not provided with a bed except when specially required. As a rule the generator is mounted directly upon the bed plate of the engine.

The bearings are of the modern self-aligning and self-oiling type. The yoke of the field magnets is of soft steel, the field being cast in two semicircular halves bolted together. The pole

pieces and their shoes are solid castings of steel, their surfaces machined true; they are bolted to the field yoke or ring. The armature spider is strongly built, and its hub is extended into a sleeve which forms a very firm support upon the shaft. The commutator is built up upon this sleeve. The armature core, built up of thin sheets of fine soft steel, is bolted to the spider. This core is slotted to receive the armature windings, and air-ducts are

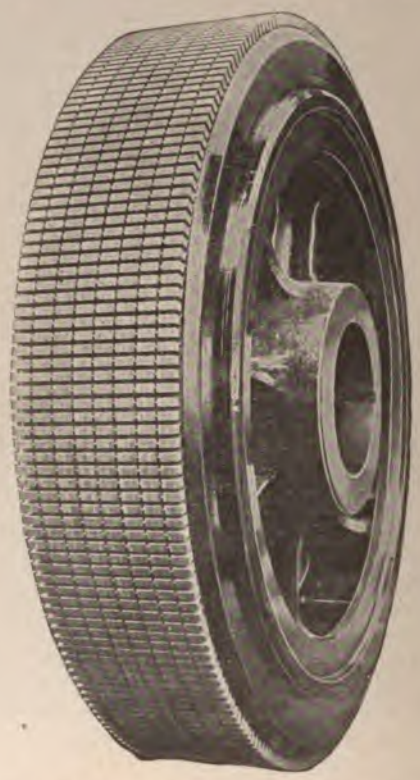


Fig. 14. Core of Westinghouse Armature.

left throughout the core for ventilation. The commutator is made up of rolled copper bars and is very large, giving good wearing qualities.

Fig. 32 shows the **Northern Electrical Mfg. Co.'s** generator without bearings, for mounting on the shaft of a steam engine. In Fig. 33 the armature core is shown separately. In Northern

machines of large size the field-magnet yoke is cast from soft steel in two pieces bolted together, while in the smaller machines the yoke is cast in a single piece. A special feature is found in the bearings. These are of bronze with an inner spiral lining of Babbitt metal. Should the Babbitt metal through neglect be permitted to heat and run out, the bronze portion of the bearings would continue to support the shaft accurately in position. Another feature of these machines is the armature locking device, by

Fig. 15. Complete Westinghouse Armature with Commutator.

means of which the armature may be mounted quickly and easily upon the shaft of an engine or turbine without tooling either the shaft or the armature bore. It is claimed that with this device the cost and time of erecting the machine is much reduced and that the armature is securely and rigidly locked in place.

The **Thresher** engine-type generator is seen in Fig. 34.

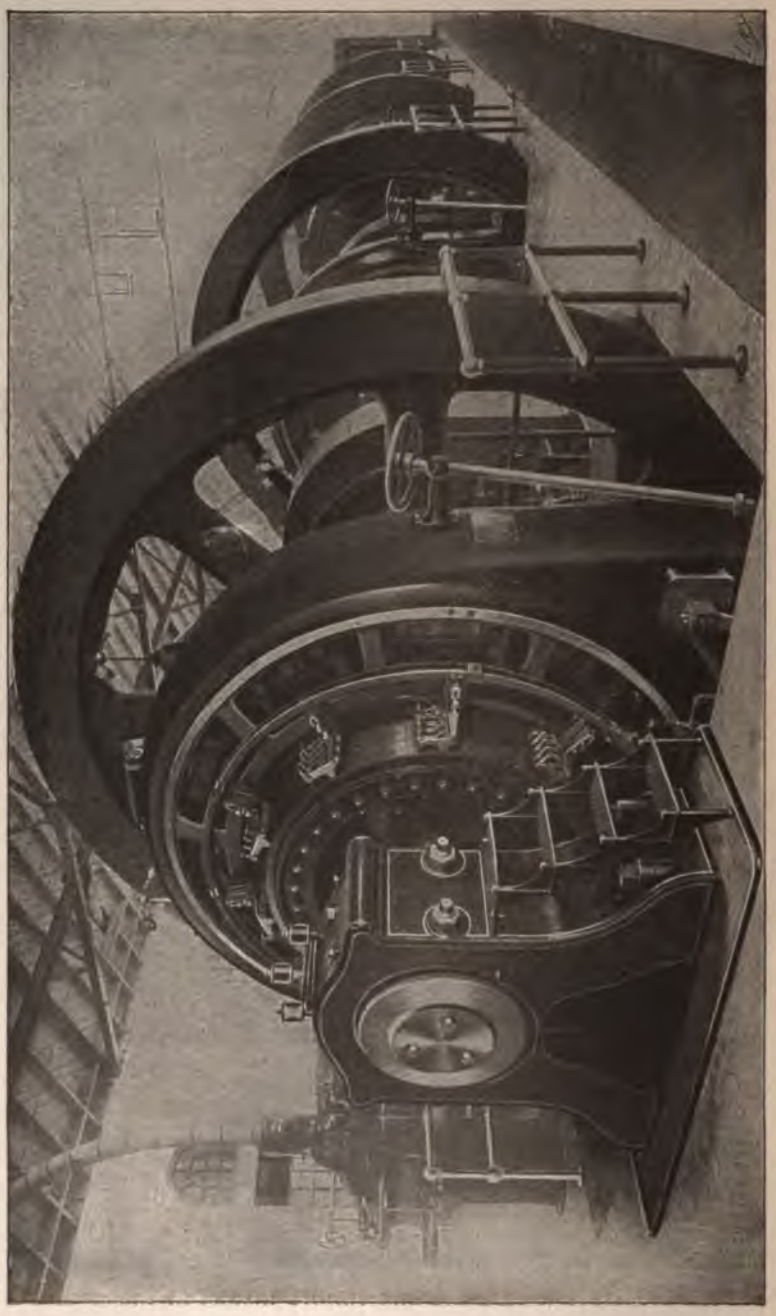


FIG. 14. Group of Westinghouse Generators.

This machine is built in sizes of from 25 K. W. to 400 K. W., running at speeds of from 325 R. P. M., in the small sizes, to 150 R. P. M. in the 400 K. W. size. The field ring is of cast iron, and the pole pieces, finished to fit accurately into recesses in the field ring, are bolted into place. The Thresher Electric Company

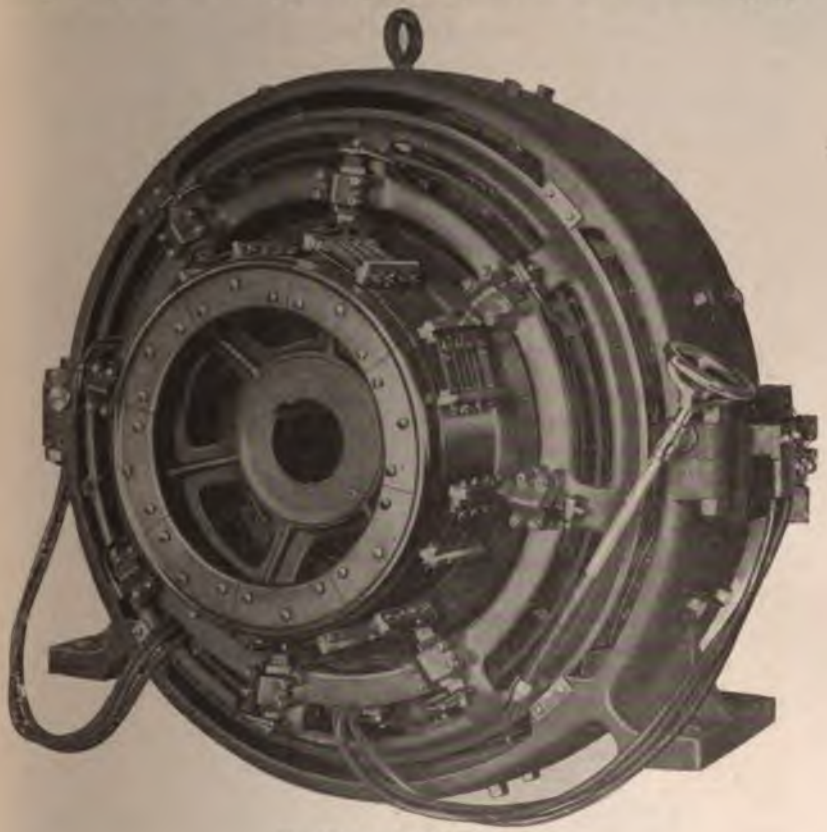


Fig. 17. Lundell Generator.

claims that a more evenly balanced magnetic field is secured in this manner than by casting.

INDIRECT DRIVEN GENERATORS.

Fig. 35 shows a typical **Westinghouse** belt-driven generator for railway service. In this figure the third or "outboard" bearing is clearly shown. Generators of this design are built in sizes of from 100 to 500 K. W., the revolutions per minute rang-

ing from 650 R. P. M. in the smallest size to 320 in the largest. The machine in Fig. 35 is of 500 K. W., while Fig. 36 shows the railway belted generator as designed in sizes of from 100 to 500 K. W. In these machines the third or "outboard" bearing is

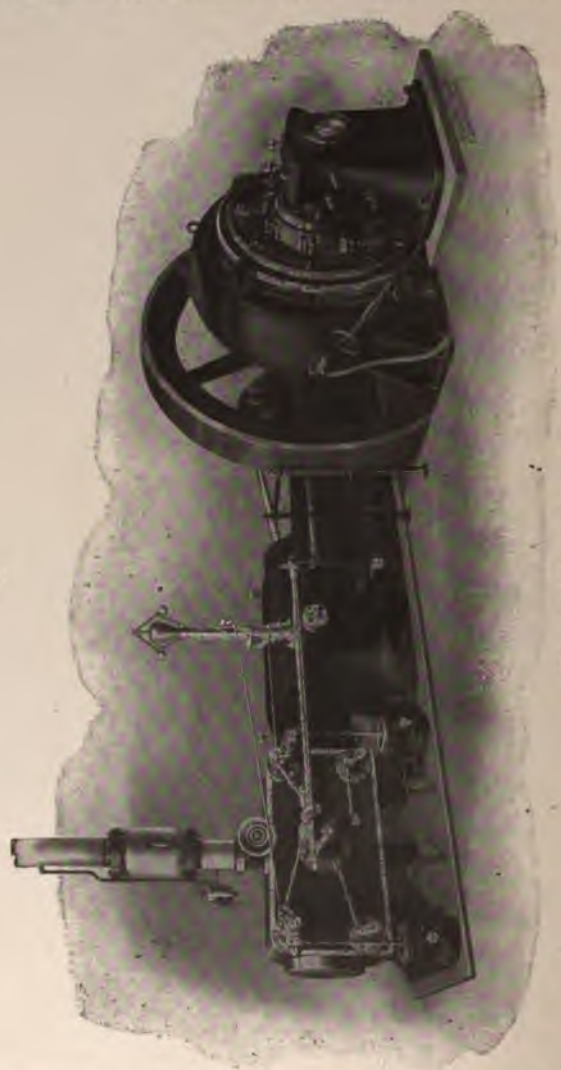


Fig. 18. Triumph Generator.

omitted, the pulley being permitted to overhang the bearing, as the belt-pull in these sizes of generator is not severe enough to occasion any difficulty by bending the shaft.

These generators are compound wound, and the winding is so proportioned that the terminal E. M. F. of the machine increases about 10% at constant speed from no load to full load. The armature core is built up of soft steel sheets, and is wound with rectangular shaped copper bars, insulated before placing upon the armature. The coils are sunk in slots in the surface of the armature core and are held in position by wedges. Fig. 37 shows a complete armature for one of the Westinghouse railway generators, and the commutator is shown separately in Fig. 38.

Fig. 19. Triumph Generator for Use on Shipboard.

The Westinghouse Company has developed a method by which the potential at all the sets of positive brushes is maintained equal. This is done by equalizer rings as already described. If it were not for these rings, even if the difference of the E. M. F. were very slight, yet owing to the very low resistance of the armature windings a heavy current would flow through the armature windings from one positive brush to another. This would upset the electrical and magnetic balance of the generator and cause wasteful heating of the armature. In fact the machine is far more efficient and more easily regulated when thus modified than

it could be if it were not balanced in some such manner. It would be practically impossible to so design and adjust the generator that precisely equal E. M. F.'s should be generated in corresponding sections of the armature windings.

Furthermore by means of this balancing method the armature

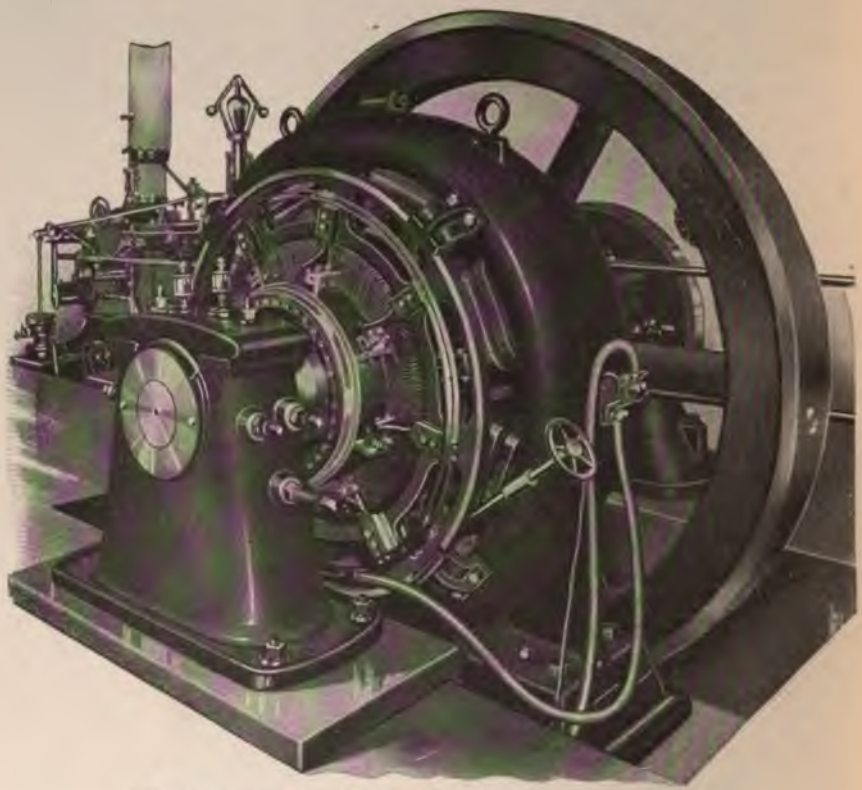


Fig. 20. Large Triumph Generator Mounted on Engine Shaft

—should it wear slightly out of centre—would still regulate easily, and the efficiency would be maintained.

Fig. 39 shows a Westinghouse belted type of generator as built in small sizes. This machine has no "outboard" bearing, as it is only of comparatively small output. It gives an electromotive force of 220 volts, and its output is 150 K. W. The design is particularly compact and symmetrical, and alto-

gether the machine is a very efficient and satisfactory one. A complete Westinghouse armature for electrolytic work is given in Fig. 40.

Fig. 41 shows one of the **General Electric** belt-driven moderate-speed generators. These are made in standard sizes that range from 4-pole 85 K. W. machines with a speed of 750 R. P. M. down to 0.75 K. W. 2-pole machines with a speed of 1200 R. P. M. In a general way, their design suggests the lines of the

Fig 21. Complete Field Frame and Pole Pieces of Triumph Generator.

direct-driven type. That is to say, the upper and lower halves of the field are cast separately, the lower casting, however, in this case being carried out at the sides to form the lower portions of the main bearings; the pole pieces are bolted into the magnet frame, and the armature is built up of laminated sheet iron, fastened

to a cast-iron spider, this construction permitting of ample ventilation; the armature windings, shown in Fig. 42, are carried in slots cut in the armature core, and the commutator is of large area, ample wearing surface and good ventilation. It will be seen, however, that the armature is of much less diameter and greater length along the axis than in the direct-driven railway machines. Fig. 43 shows the armature in process of construction.

An important feature of these machines is the self-oiling and self-aligning bearing (Fig. 44). In the illustration are seen

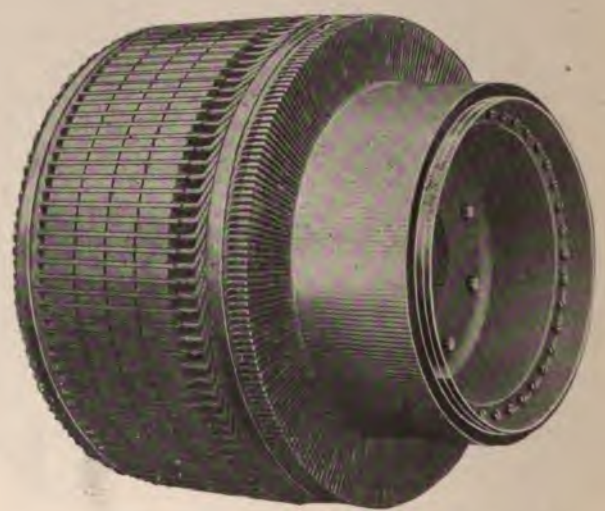


Fig. 22 Armature of Triumph Generator.

two loose rings, which hang in a reservoir of oil provided in the lower part of the casting. These rings, rotated by the motion of the shaft, continually bring up a supply of oil.

The rings are, of course, considerably larger than the diameter of the shaft upon which they are hung. There is, however, no friction between them and the shaft. On the other

hand, they cannot get out of place, being confined in position not only by grooves in the circumference of the shaft, but by the upper and lower halves of the case. Oil which is thus enclosed and fed copiously to the shaft may be used with very little wastage for a considerable period of time, and the lubrication secured in this simple and convenient manner is probably more thorough than that obtained in any other way. The shaft not only receives sufficient oil for lubrication, but is, as it were, drenched in oil, which drips continually from it, helping in no small degree to carry away the heat and thus keep the shaft and bearings cool. The oiling of bearings by means of loose rings is now used on a number of the leading types of generators and motors, although a number of our illustrations show oil-cups of the familiar pattern in use upon generator and engine shafts.

Fig. 45 shows the **Crocker-Wheeler** belt-driven generator, looking from the commutator end. In general, these machines conform to the standard type of moderate speed generator. The regular standard sizes range from 200 K. W., operating at 350 R. P. M., down to 9 K. W., operating at 1025 R. P. M. Fig. 46 shows the form of the field magnet frame or yoke, together with the field poles and polar faces. The magnet frame is of cast iron split horizontally, to facilitate assembling and removal in case of injury. The poles are "cast welded" into the magnet frame. That is to say, the poles are constructed first, and are placed accurately in position in the mould in which the field magnet frame is to be cast. The molten metal for the magnet frame flows around the ends of the magnet poles, in this way making a magnetic joint. This method is also a characteristic of some of the Westinghouse machines.

If the "cast-welded joint" is perfectly made, there is no doubt that it will give a better magnetic circuit than would ordinarily be obtained by the method of bolting. There is, however, some difficulty in securing a perfect welding of the metallic surfaces, but this difficulty is now in great part overcome.

Fig. 47 illustrates the **Fort Wayne** belt-driven generator with outboard bearing.

Fig. 48 shows the **C & C Electric Company's** belt-driven generator with overhanging pulley. This generator has 6 poles,

and its general construction resembles that of the engine-type C & C generators previously described. The belt-driven type is made in

Fig. 23. Fort Wayne 400 K. W. Generator.
Showing Hand-Wheel for Shifting Brushes

standard sizes of from 30 to 175 K. W., running at speeds of from 275 to 450 revolutions per minute. The C & C brush holders

are of special patented construction. The carbon brushes are inclined at a slight angle from the radial line, and it is claimed that with this design of brush the direction of rotation of the armature may be changed without altering the position of the brushes and without sparking.

Fig. 49 shows the **Bullock** belted generator of the multipolar direct current type. The massive construction of the

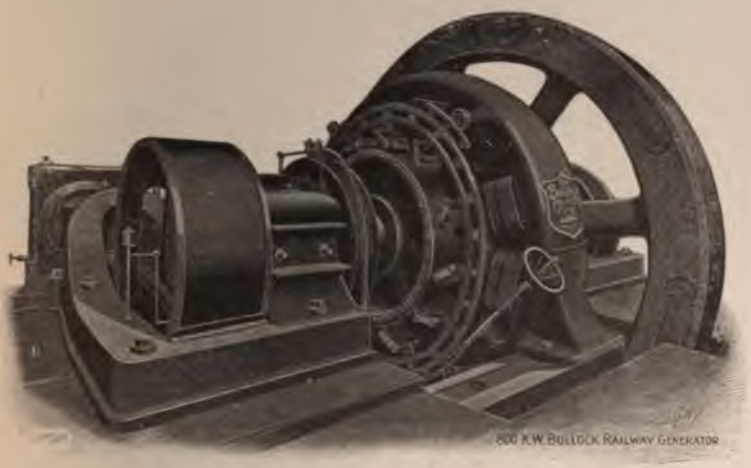


Fig. 24. Eight Hundred K. W. Bullock Generator.

machine is evident. A feature of special interest is the enormous belt pulley provided. This pulley is carried by the shaft between one of the main bearings of the generator and a third or "outboard" bearing. The base plate of the generator rests upon three rails or sub-bases of cast iron, and the belt is adjusted by sliding the machine bodily along these rails by means of the adjusting levers shown. These levers are connected together by a bar, and are worked by a ratchet gear, which insures that both ends of the machine shall be moved through equal distances.

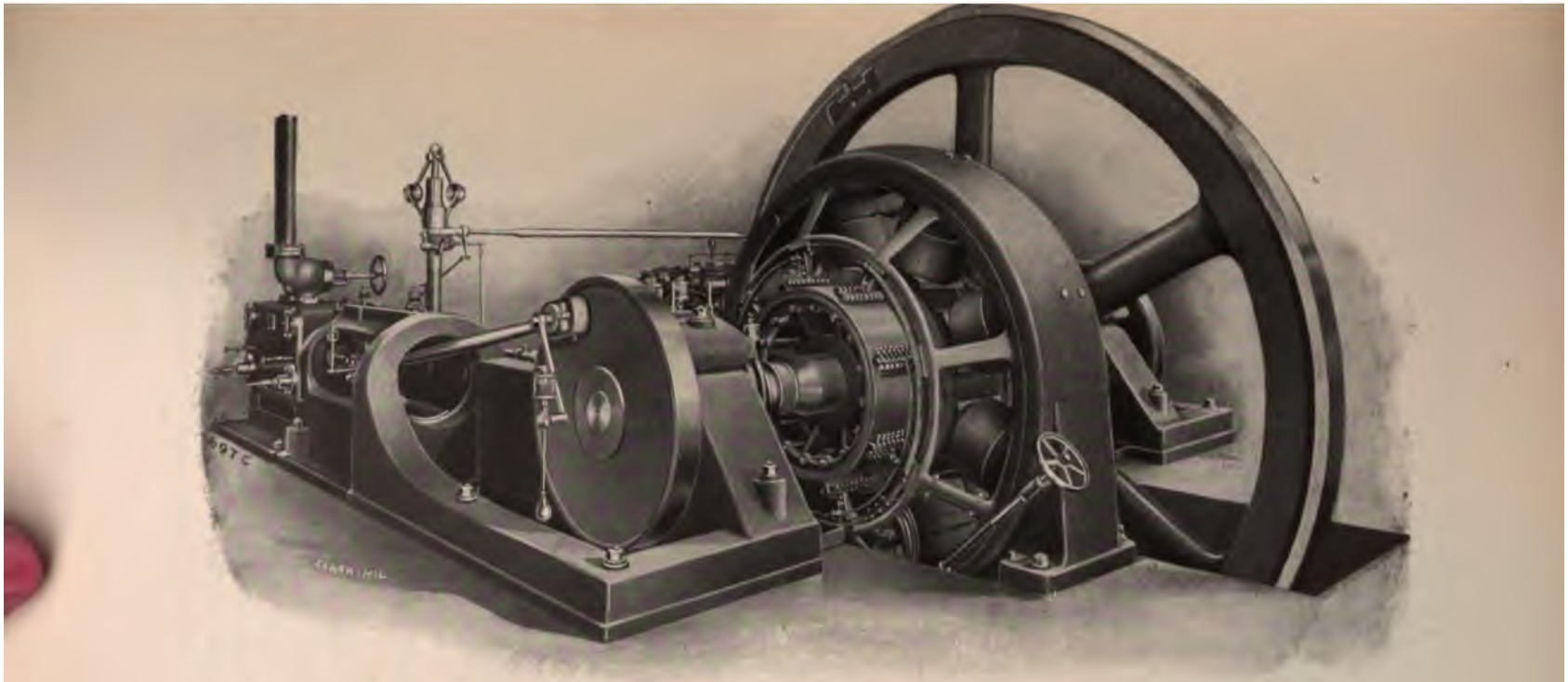
Fig. 50 shows the belted multipolar generator made by the **Western Electric Co.**, and Fig. 51 shows a similar machine by the same company. The bipolar machines are made up to 3 K. W., and the regular multipolar machines of the type shown

run up to 250 K. W. The lower half of the frame of the multipolar machines, together with the base and the pedestals, are in one casting, while the upper half of the frame is also a single casting. In the smaller machines the frame is cast in a single piece. Slide rails are used, and the belt is tightened by means of the chain and ratchet.

The armature is of the iron-clad type, having bare conduct-

Fig. 25. Spider for Bullock Armature.

ors imbedded in insulating tubes below the surface of the core, no band wires being used. The insulating tubes are made up of alternate layers of pressboard, oil-paper and mica. The armatures are stated to be perfectly balanced both mechanically and electrically, so that they will operate without vibration. Provision is made for ventilation in the usual manner by the use of air-ducts through the armature core.



"NATIONAL" ENGINE-TYPE GENERATOR

200 K.W. 250 Volt, 135 R.P.M.

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The pole pieces, which are bolted to the field frame, carry well ventilated and insulated machine-wound coils.

The commutator is large, having high conductivity and long life. The brushes are of carbon, and may be separately removed or adjusted independently while the generator is in operation.

Fig. 52 shows the **Holtzer-Cabot** belt-driven multipolar generator, embodying the salient features of recent design: slow speed, compactness, massive armature and commutator con

Fig. 26. Complete Bullock Armature.

struction, high efficiency, cool running, etc. Fig. 53 shows the base, field ring, field cores and pedestals, with journals and brush holders. The armature is seen in Fig. 54. Fig. 55 illustrates the construction of the armature core before the windings have been placed in position; it also shows at the right the completed commutator, and the lugs by which the armature windings are to be brought into connection with the commutator segments are clearly seen.

The shaft is massive, and all moving parts show sound mechanical design. Fig. 56 shows the armature in process of winding, and in Fig. 57 is seen the commutator complete in itself, but not yet placed in position upon the armature shaft.

In the design of dynamo-electric machinery the amount of current carried by the conductors is determined by standard prac-

tice, and is calculated in amperes per square inch of cross-section of conductor. Thus armature conductors as ordinarily calculated carry 2,000 to 3,000 amperes per square inch of cross-section. For instance a, round armature wire one-half inch in diameter will carry 392 to 589 amperes, and so on.

Similarly in figuring commutator capacity a definite figure must be fixed for the amount of current to be carried per square inch of cross-section of commutator segment. A figure must also be determined for the current carried per square inch of surface of the brushes where the brushes make contact with

Fig. 27. Eight Hundred K. W. Bullock Generator Disconnected from Engine.

the commutator. These figures vary somewhat among the different manufacturers. In the Holtzer-Cabot machines the carbon brushes are designed to carry 25 amperes per square inch of cross-section when the machine is carrying full load. Copper brushes may carry 175 amperes per square inch of contact surface. This is conservative design, and provides such ample surfaces of contact that the commutator is certain to run without heating at all loads.

It is at first sight surprising that such massive designs should be necessary in brush construction, but it should be remembered that the efficiency of the machine depends upon keeping the resistance of the armature at the lowest possible point. There is always considerable resistance at the point of contact of brush

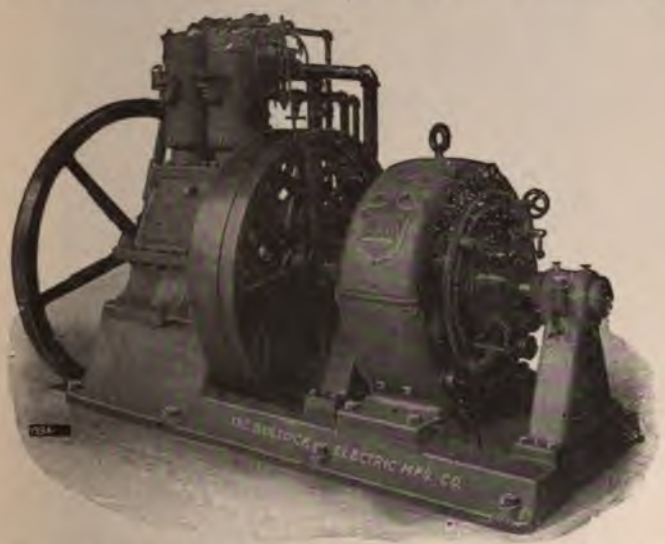


Fig. 28. Fifteen K. W. Bullock Generator Connected to Gas Engine.

and commutator, and this resistance can be kept within small limits only by making the total cross-sectional area of the brushes very large compared with the other conductors of the machine.

The **Lundell** single-coil belted generator is seen in Fig. 58. It has a single field coil embracing closely all of the pole pieces, magnetizing them directly.

Fig. 59 shows the **Northern Electric Mfg. Co.'s** belt-driven generator. The strong pedestals and ample bearings should be noted, as also the rigid base, the convenient arrangement of the brush regulating wheel and the unusually wide pulley. The illustration gives an excellent view of the "outboard" bearing previously noted.

The **Thresher** belt-driven generator is shown in Fig. 60. The machine rests on slide rails and the belt is adjusted by

sliding the generator forward or back upon the rails, thus tightening or slackening the belt. The ratchets by which this is accomplished are seen in the illustration coupled together to

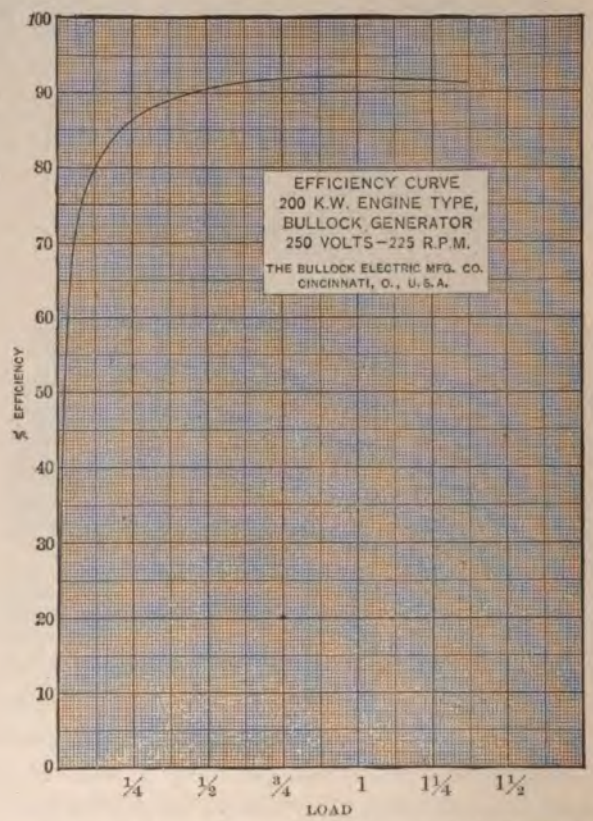


Fig. 29. Efficiency Curve of 200 K W. Bullock Generator.

insure equal motion of both ends of the generator base, and a lever for manipulating the ratchet gear is also seen.

GENERATORS FOR ELECTROLYTIC WORK.

Generators for electrolytic work have recently been developed to a high degree of mechanical and electrical excellence. In treating of the "Elements of Electricity" we discussed the general principles involved in electrolysis. In commercial electrolytic work (such as electrotyping, electroplating and many

chemical manufactures) a very powerful current flowing at a low electromotive force is needed as a rule. Electrolytic generators accordingly are required to give an extremely low E. M. F., since any E. M. F. in excess of that required for the electrolytic bath would be wasted, having to be absorbed by series resistances. Only a slight surplus E. M. F. is provided for regulation of the current.

Fig. 61 shows the **Westinghouse** direct-connected generator for electrolytic work. It is a multipolar direct current gener-

Fig. 30. Bullock Generator for Use on Shipboard.

ator giving a low E. M. F., but having a very large output in amperes. . In fact, the current is so great and the E. M. F so small that it is necessary to take extraordinary precautions to keep down the resistance at the commutator. It will be seen that the armature carries two commutators, each of very large area and fitted with an unusual number of brushes. There is only one armature winding, the two commutators being therefore in parallel. That is to say, an armature coil at the point of tapping off is connected by massive connecting bars to a segment of each commutator. The two sets of brushes are regulated independently by means of the two hand-wheels seen in the illustration.

The circuits derived from the two commutators may be separately applied to outside work or may be united in simple parallel.

Fig. 62 shows the armature with double commutator for a Westinghouse electrolytic generator. The generator illustrated is shunt wound, with an output of 4000 amperes.

ARC LIGHTING GENERATORS.

Arc lamps are in many cases supplied by an alternating current of high potential. This method will no doubt continue in very general use, but installations of arc lamps are now very common on direct current circuits of both high and low potential. On low potential circuits two arc lamps are often run in series (as, for example, from a 110-volt circuit). Thus 100 lamps would be connected up in 50 parallel rows, each row containing two lamps in series. On high potential direct current circuits the lamps are all in series, or else there are several parallel rows of lamps, each row having a considerable number of lamps in series. This latter arrangement, modified, is explained more fully in discussing the General Electric arc lighting generator.

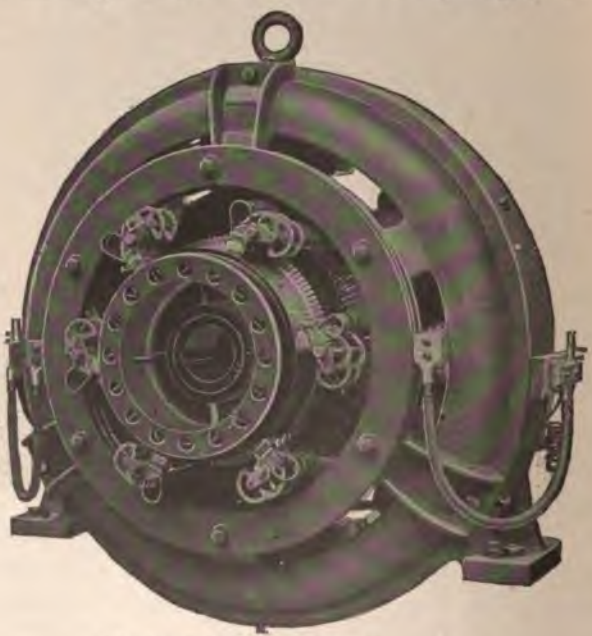


Fig. 31. C & C Engine-Type Generator.

High potential direct current arc lighting generators are manufactured by several prominent companies, and we give a few leading types.

Fig. 63 shows the **Westinghouse** direct current high potential arc lighting generator designed for belt driving, for 75 arc lights. In general construction it resembles the other Westinghouse multipolar generators and like them has self-oiling and self-aligning bearings. The machine illustrated operates at 825 R. P. M., giving 6.8 amperes at 3750 volts.

The generator is of the open coil type giving a current which, while constant in direction, is not absolutely continuous. The result is a pulsating current which causes a very slight vibration of the feed mechanism of the lamps. This prevents sticking of

Fig. 32. Northern Electrical Mfg. Co.'s Multipolar Generator.

the feed, but is far too slight to effect the steady, uniform intensity of the light. In Fig. 64 is shown the armature partially wound. The coils are being forced into position upon the laminated and slotted armature core. The complete armature is shown in Fig. 65. The commutator for the open coil winding is seen at the extreme right; and at the extreme left, as also between the armature and commutator, are seen loose rings hanging from the

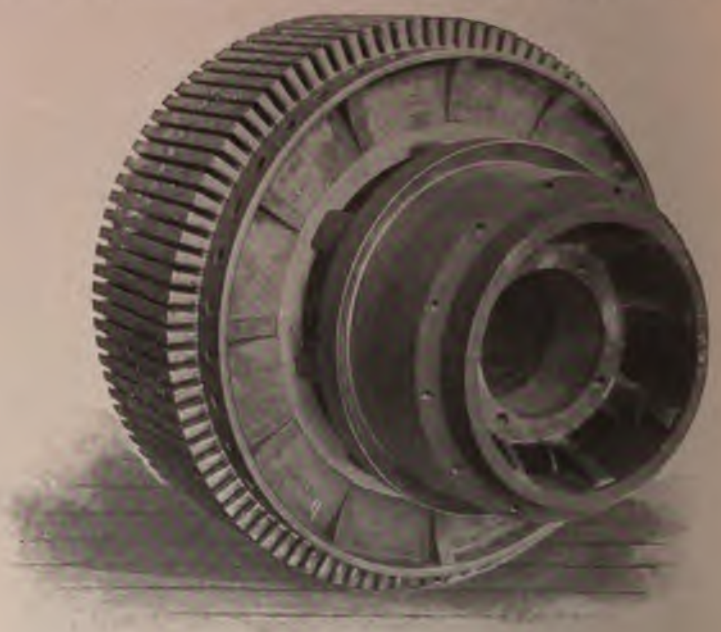


Fig. 33. Armature Core of Northern Generator.

shaft. These are the rings which dip into the reservoirs of oil provided for in the bearings. As the rings rotate with the shaft they continually draw up a fresh supply of oil, thus keeping the bearings thoroughly drenched.

The Westinghouse direct current arc lighting generator is excited by means of a small direct current machine furnishing a 100-volt current. This practice frees the field windings from the chances of grounding and makes the handling of the machine much safer. A feature of these machines is that the armature coils are easily removed and replaced It is not necessary there-

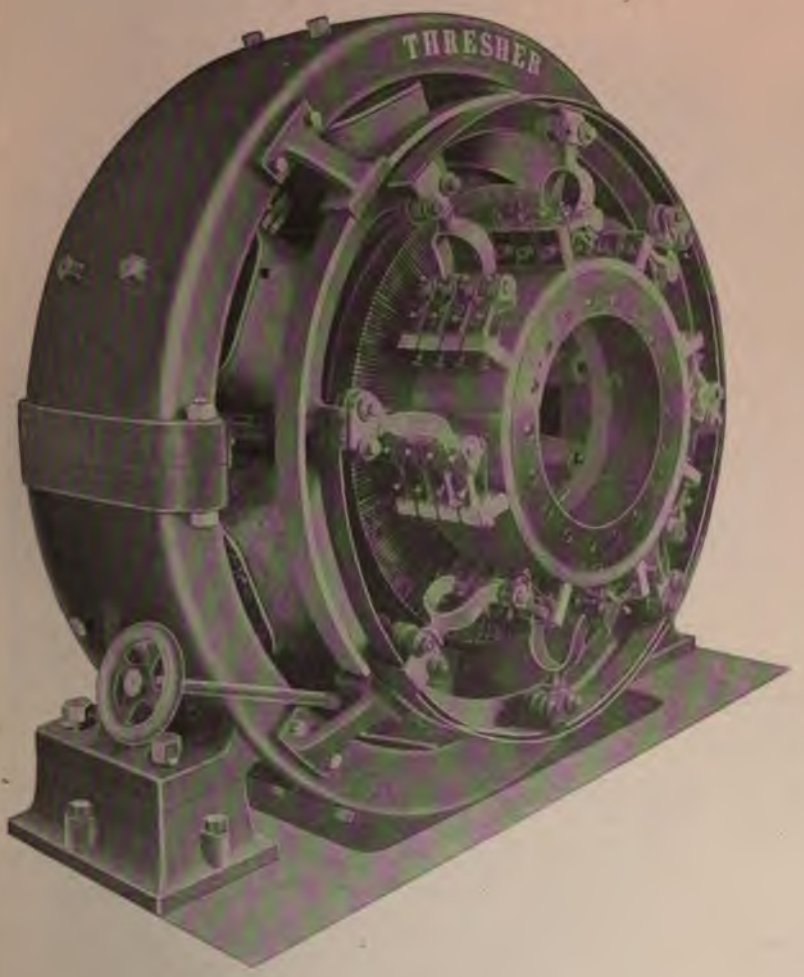


Fig. 34. Thresher Engine-Type Generator.

fore to keep on hand an extra armature, since an injured coil may conveniently be removed and a fresh one substituted.

The **General Electric** direct current arc lighting generator appears in Fig. 66. This is a modern development of the historical Brush generator and is of the same general type embodying

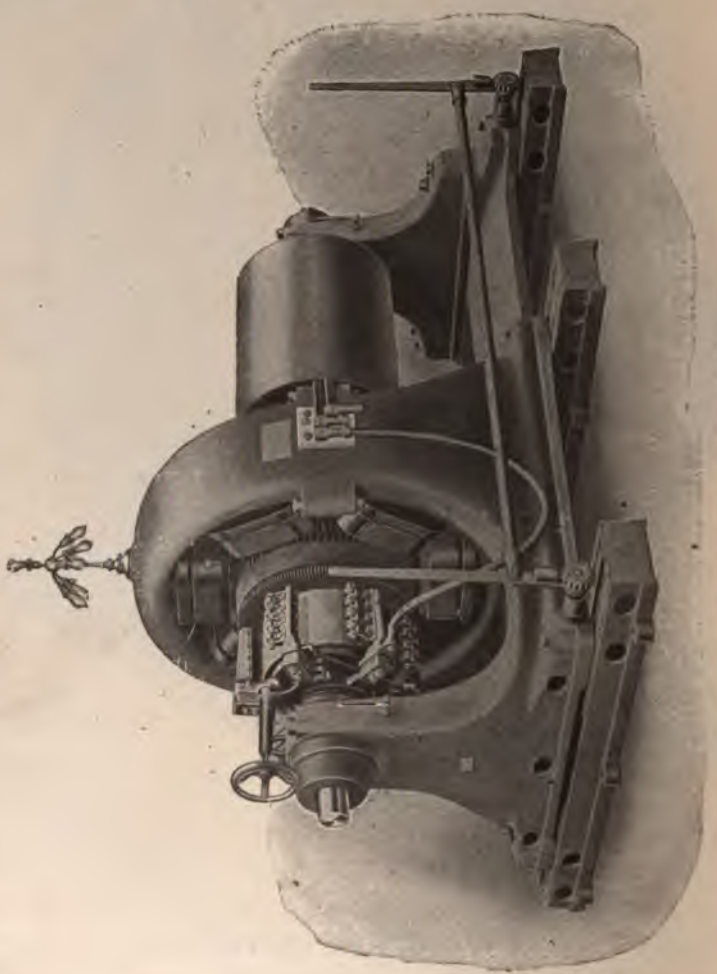


Fig. 33. Westinghouse Belt-Driven Generator.

the same general principles. The modern machines however, in distinction from earlier types, operate on the "multi-circuit" arrangement. Upon the shaft of the armature are mounted a

number of separate commutators, each properly connected to the armature windings and supplying separate groups of lamps on

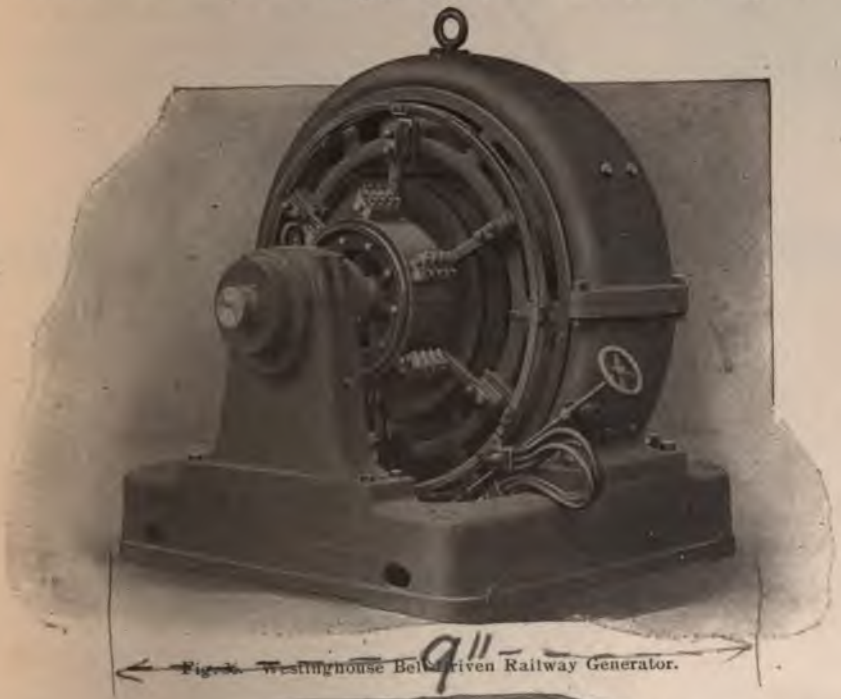


Fig. 36. Westinghouse Belt-driven Railway Generator.

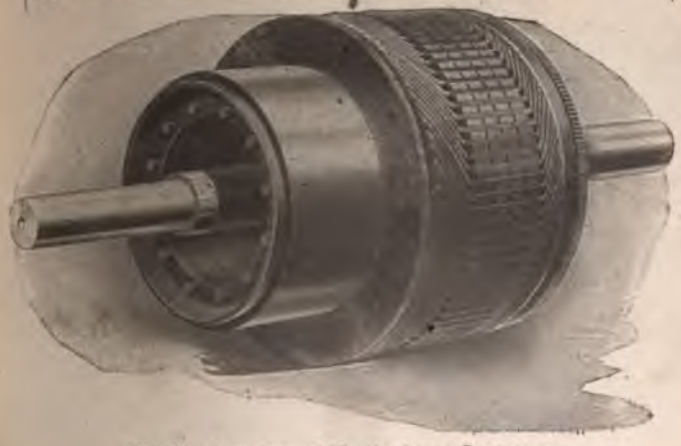


Fig. 37. Armature of Westinghouse Generator.

separate mains. Nearly 100,000 arc lights are now supplied by large-size General Electric generators of this type.

Fig. 38. Westinghouse Commutator.

Fig. 39. Westinghouse 150 K. W., 220-Volt Generator.

The student will have seen from the foregoing pages that the modern types of generator are more and more tending to large size; and the same is true, though to a less extent, in regard to motors. The designs now in hand by the larger electrical companies indicate that the next few years will see dynamo-electric

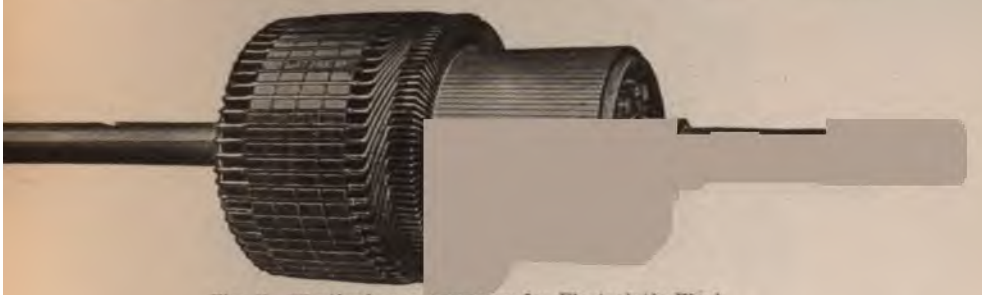


Fig. 40. Westinghouse Armature for Electrolytic Work.

machines of still larger dimensions. In fact, it is difficult to see at present any practical limits to the size of the electric generator.

This growth in size as well as in numbers is due to numerous causes. The increased demand for electric energy has, of course,

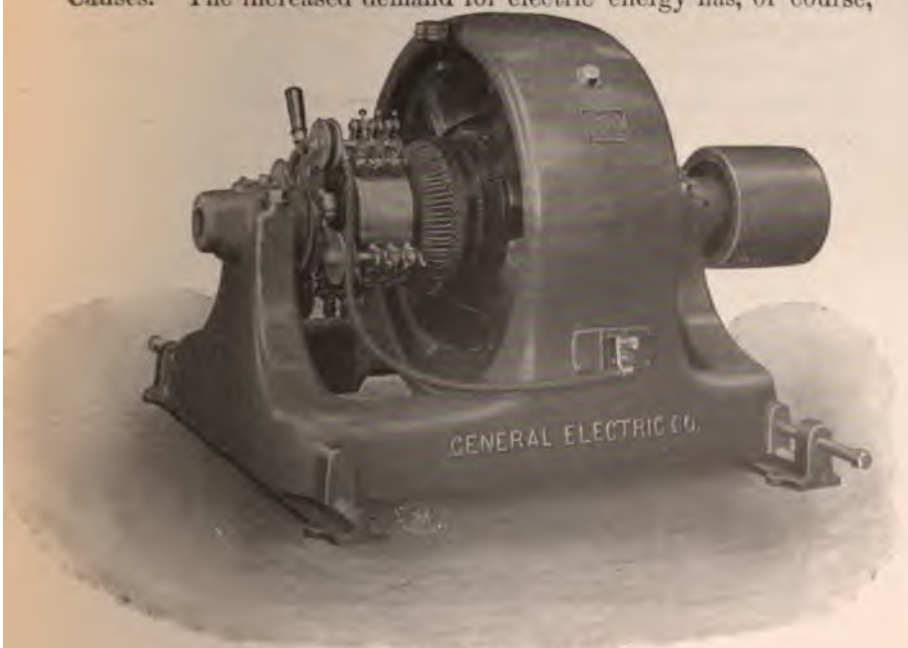


Fig. 41. General Electric Co.'s Belt-Driven Generator.

had an influence on the design of the large modern machines. Also there is a greatly increased economy of construction in equipping a plant with a few large machines in place of a large number of smaller units. Obviously, in designing a station the engineers

Fig. 42. General Electric Armature.

endeavor to plan the installation so that the generators shall run during a large part of the time at or near full load. This is done because the generator works at better efficiency when at or near full load. Hence, as the demand for electric energy increases, generators of larger size are built. Commercial machines, running at their full output, and necessarily tending to become

Fig. 43. General Electric Armature, Unfinished.

Fig. 44. General Electric Self-Oiling Bearing.

Fig. 45. Crocker-Wheeler Belt-Driven Generator.

heated, require unusual facilities for ventilation, and such ventilation can only be secured by a design which affords massive metallic bodies for conducting and radiating away the heat generated, and in which ample air spaces are left. The student will see in the following pages that these same considerations have held in the case of the electric motor, but to a considerably less

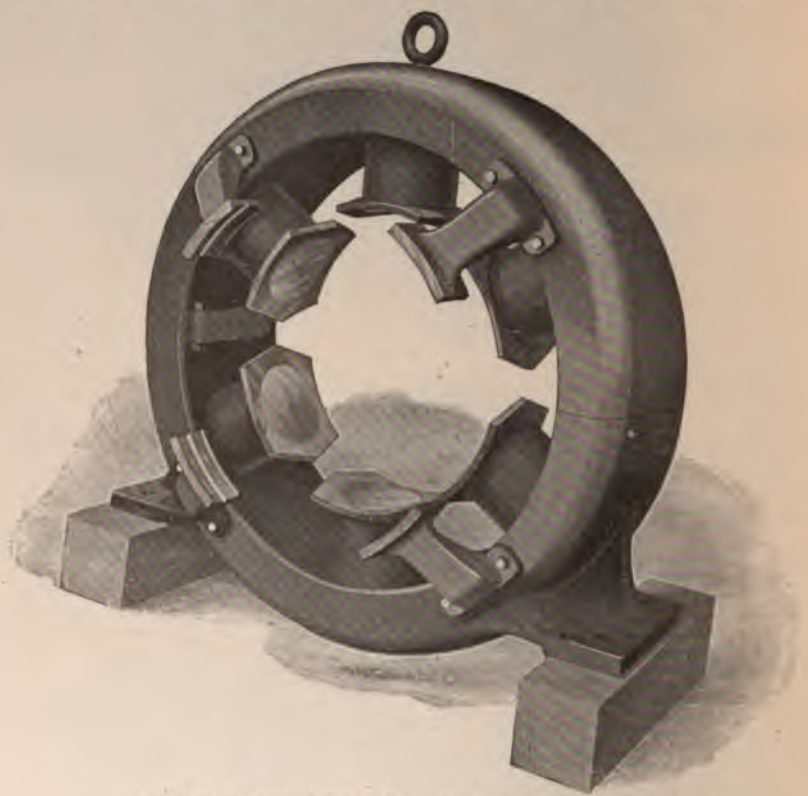
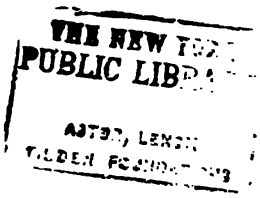


Fig. 46. Yoke and Poles of Crocker-Wheeler Generator.

degree, inasmuch as the conditions under which motors and generators operate are so different.

The direct current generator and motor have hitherto held the foremost place in electrical supply systems, and they are continually being improved in design and construction, so that every year adds something to their efficiency and mechanical excellence. Although direct current machines are becoming higher and higher in grade, they are no longer foremost in the electrical world.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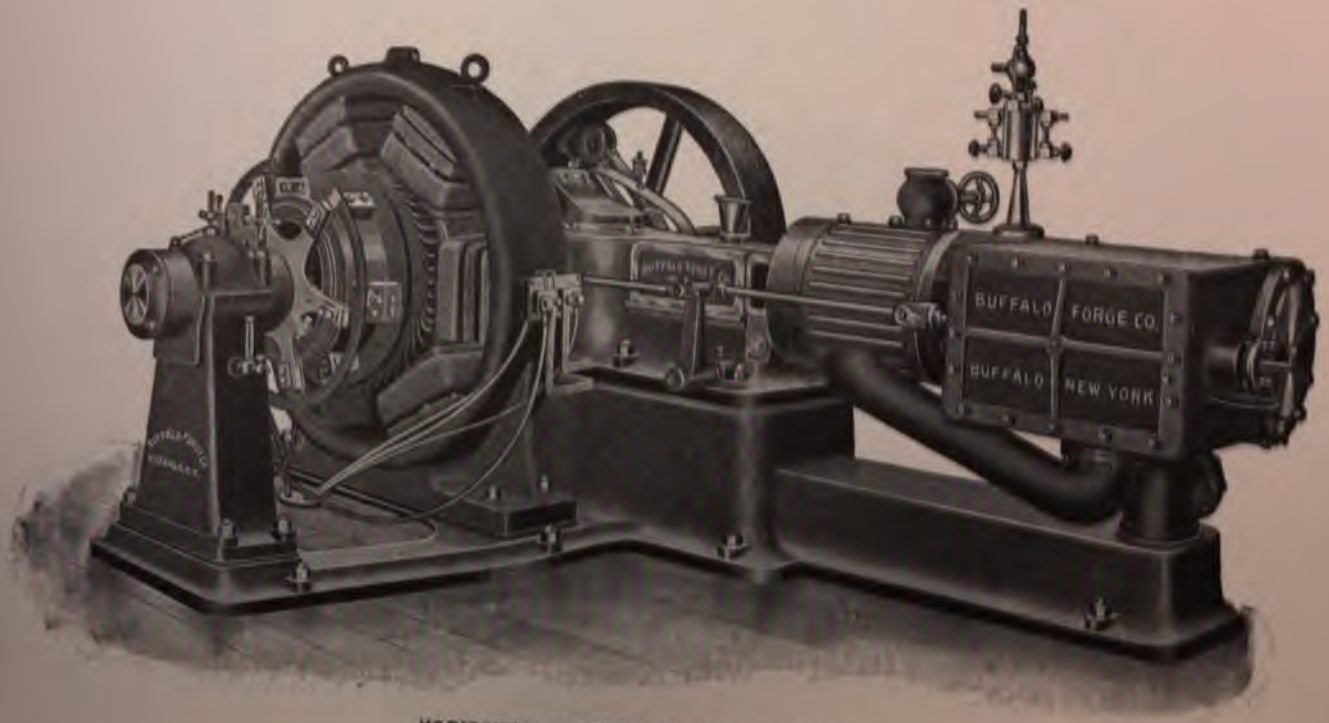


HORIZONTAL TANDEM-COMPOUND ENGINE.
Direct-Connected to Generator.
Buffalo Forge Company.

Within the last five years the alternating current motor has developed so rapidly that it is now a practical and reliable piece

Fig. 48. C & C Electric Co.'s Belt-Driven Generator.

of apparatus, and is coming very rapidly into use for a great variety of applications. Therefore, in studying the present Paper the student should bear in mind that the types here shown, although they are growing in size and number every year, are not

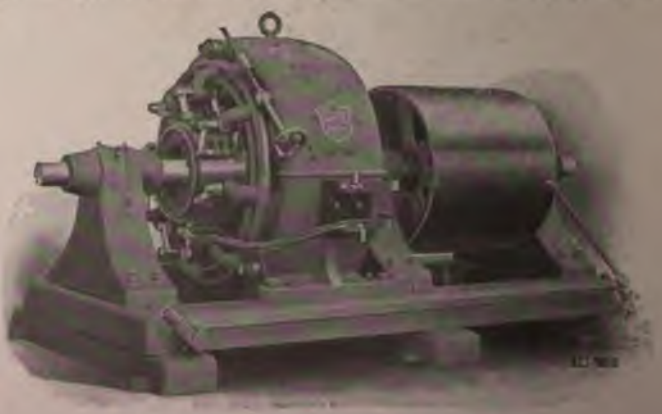


Fig. 49. Bullock Belt-Driven Generator.

holding their own against the newer system of polyphase electric transmission. The polyphase current systems are described in subsequent Papers, and the student will do well to give them careful attention. The alternating current is better adapted to long distance transmission, because it can be conveniently generated and transmitted at far higher voltages than are ordinarily possible in direct current work. And, of course, the use of a high voltage permits the use of smaller currents for transmitting

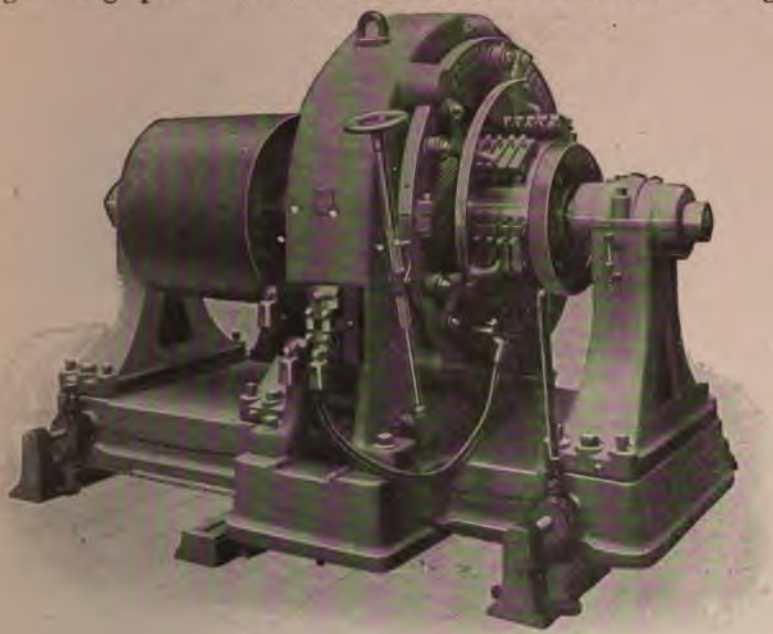


Fig. 53. Western Electric Co.'s Belt-Driven Multipolar Generator.

a given amount of energy. There are, however, many classes of service in which the direct current is preferable, and in which it will, no doubt, continue to be used for many years to come. Such classes of service are, for example, the supplying of power to small consumers in the immediate neighborhood of the generating station, and the operation of electric cars. The student must bear in mind the limitations of the direct current system, in order that he may be able to choose intelligently between the two. He should give the preference to the direct current system whenever the conditions seem to justify such choice, because of the greater

convenience, safety and simplicity of a direct current installation, but he should adopt the alternating current system when the transmission of a direct current would be marked by undue losses in the transmission line. We shall go more fully into the characteristics of alternating current work in subsequent papers. At present the student should make himself thoroughly familiar with the direct current methods as a basis for subsequent study of alternating current machinery.

Fig. 51. Western Multipolar Generator.

The following portion of this Paper is devoted to a discussion of Direct Current Motors, the motors being grouped under a separate heading, in order that they may be better compared with one another. It should be borne in mind, however, that the essential difference between a motor and a generator is slight. Of the motors illustrated here, practically any one may be driven

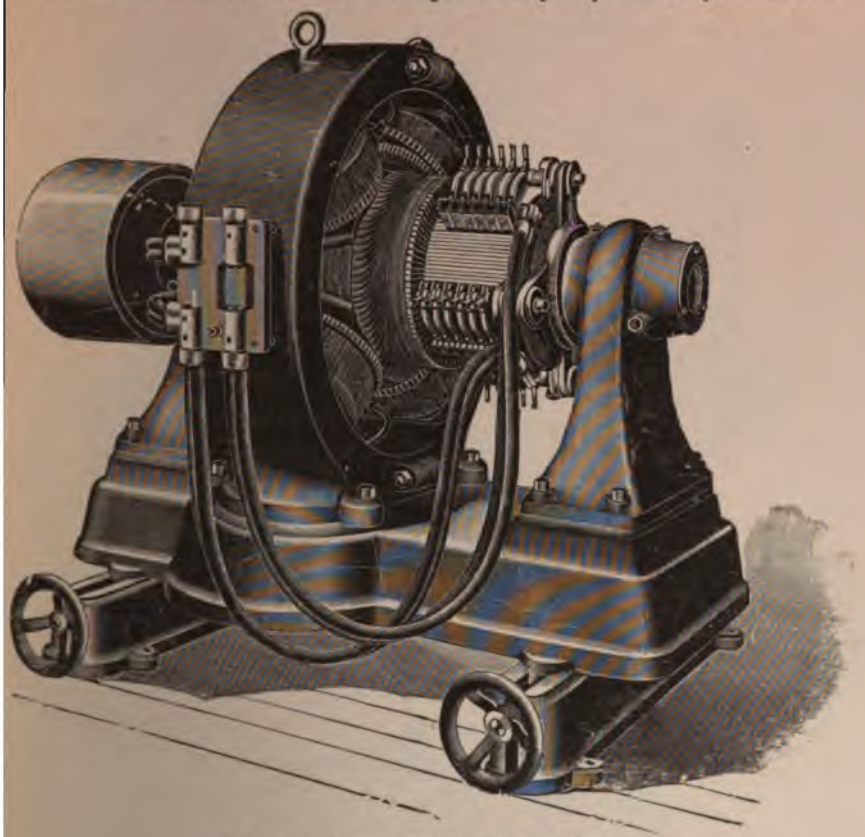


Fig. 52. Holtzer-Cabot Belt-Driven Generator.

as a generator by some outside source of power. It will then give out a current corresponding in quantity and voltage to that supplied to it when running as a motor, provided the conditions are kept constant and the same speed is maintained.

The principal difference between the two cases would be a readjustment of the brushes to suit the changed direction of rota-

Fig 53. Detail Parts, Holtzer-Cabot Generator.

Fig. 54 Holtzer-Cabot Armature.

Fig. 55. Holtzer-Cabot Armature Core.

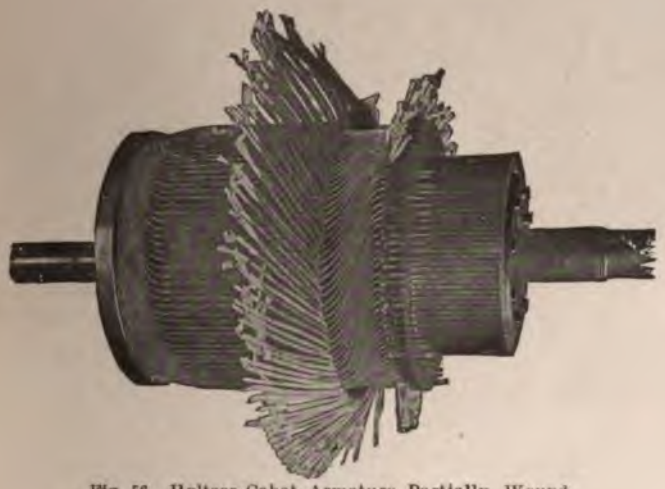


Fig. 56. Holtzer-Cabot Armature Partially Wound.

Fig. 57. Holtzer-Cabot Commutator.

tion, or a different connection to the outside circuit. In fact, some of the machines which are shown in the following pages are put upon the market not only as motors, but as generators. In

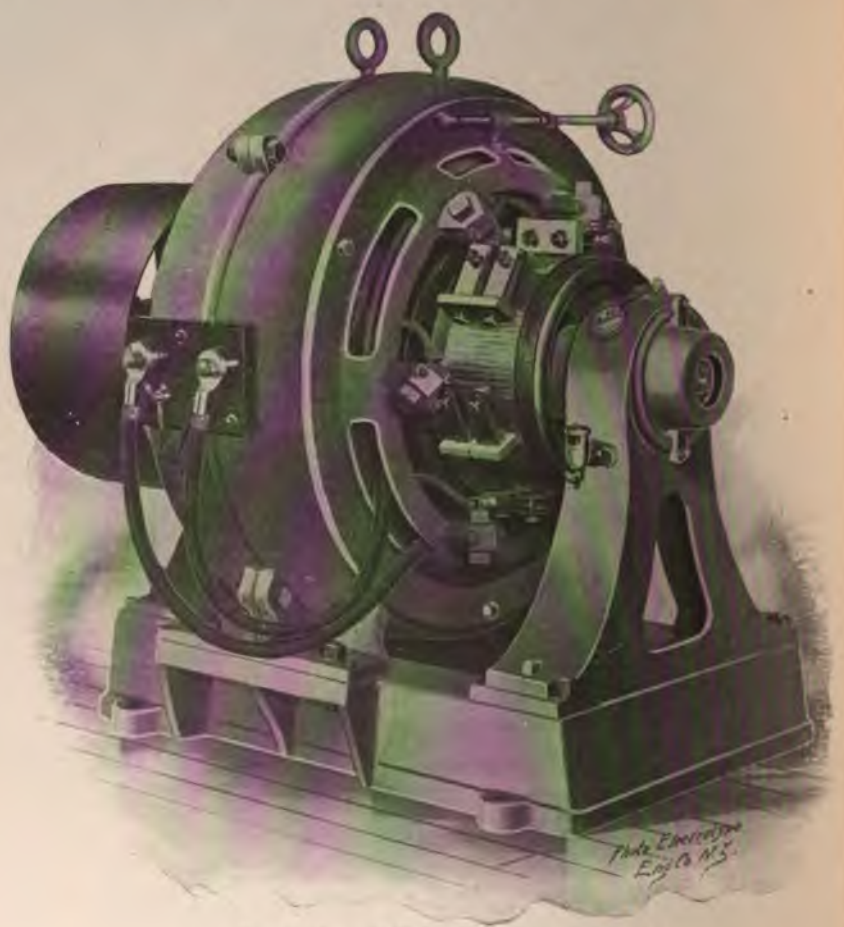


Fig. 58. Lundell Belt-Driven Generator.

most instances, however, the generator is designed for adjustment to a rigid base, whereas motors are frequently used on cars, cranes, or for other nonstationary applications.

Also, the ordinary motor is smaller in size than the average generator, since for economy in supply it is customary to design

one generator to furnish current for a large number of motors. In fact, this is one of the principal considerations which determine the difference in design between generators and motors.

The generator, being usually built for continuous running, requires ample ventilating area, whereas some types of motor are

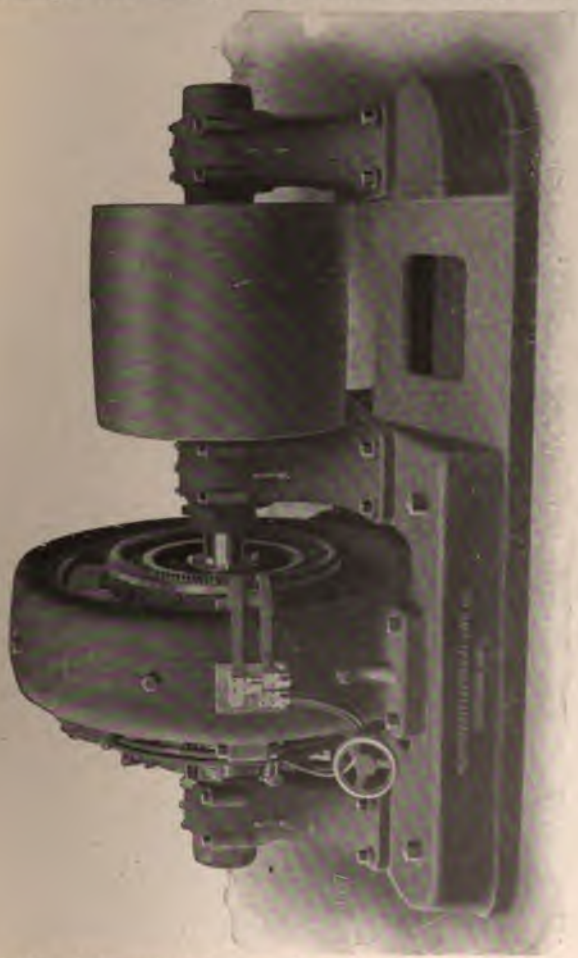


Fig. 59. Northern Belt-Driven Generator.

designed for intermittent running, and ventilation is comparatively unimportant. All motors for shop use should be so designed that they may be readily transferred from one position to another, and should have a range of speeds that would not be necessary in a generator.

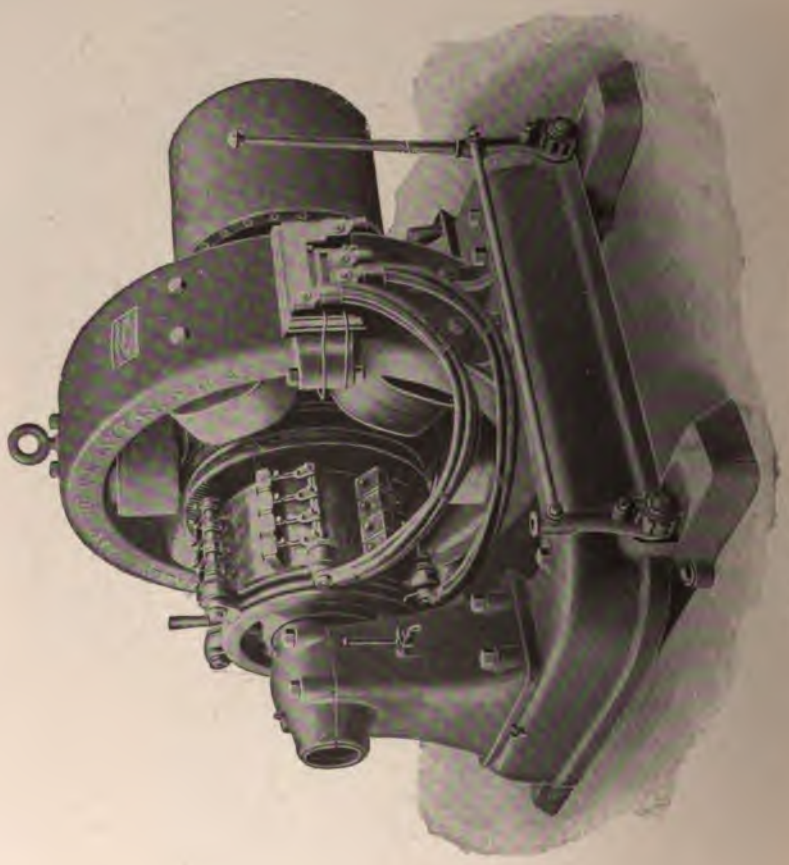


Fig. 60. Thresher Belt-Driven Generator.

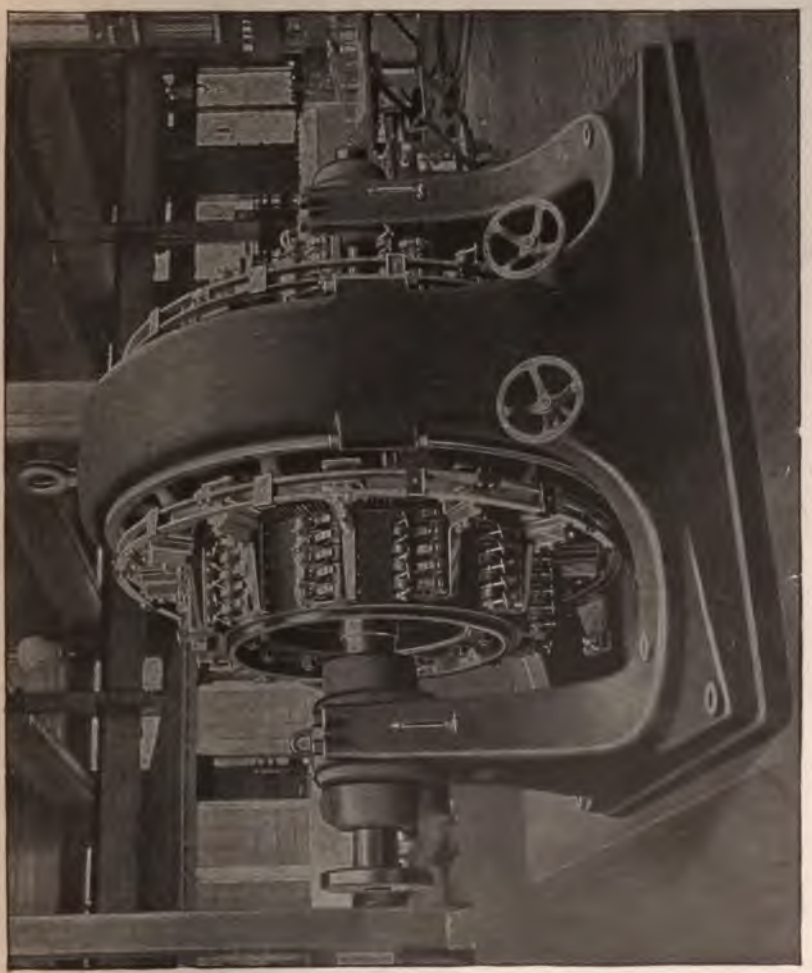


Fig. 61. Westinghouse Direct Current Generator with Two Commutators for Electrolytic Work.

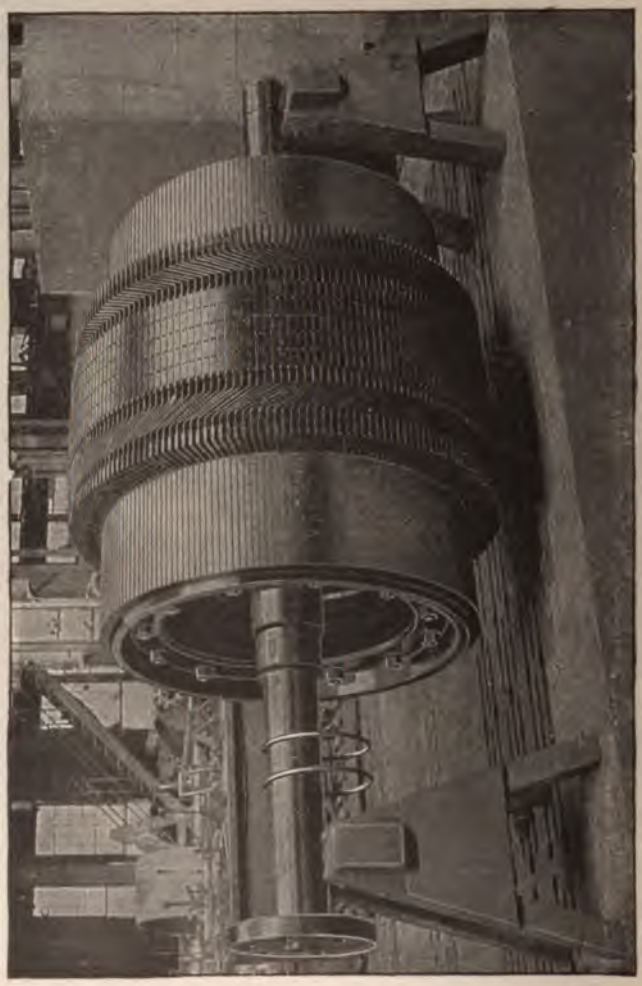


Fig. 62. Westinghouse Armature with Two Commutators for Electrolytic Work.

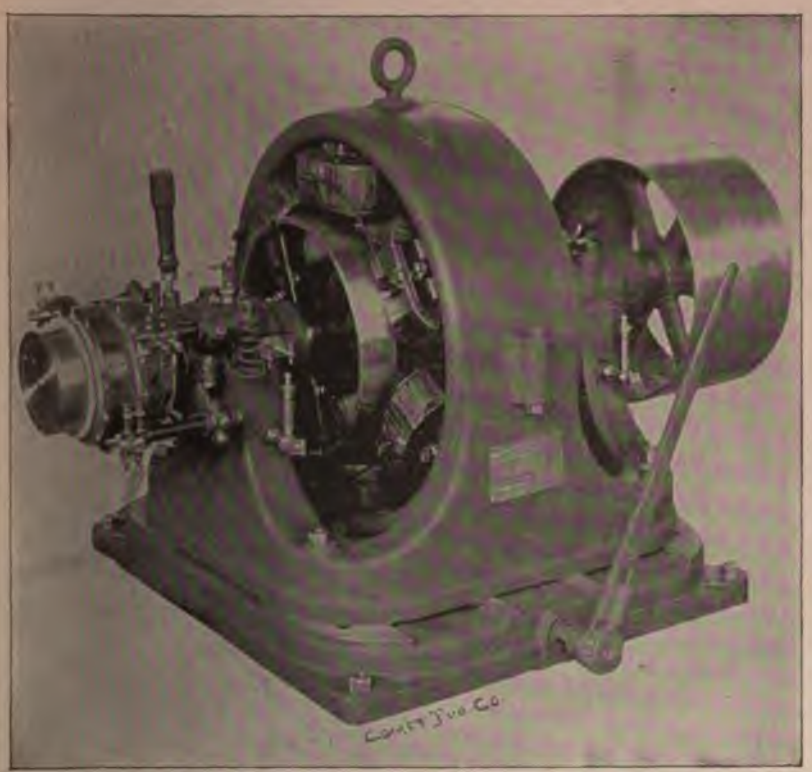


Fig. 63. Westinghouse Direct Current High Potential Arc Lighting Generator.

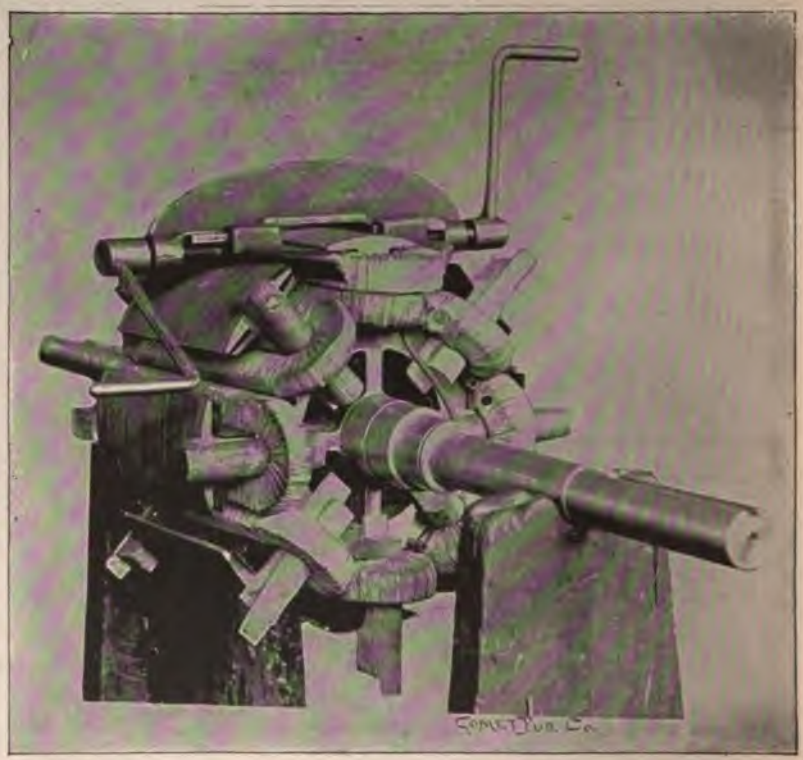


Fig. 64. Armature of Westinghouse Arc Lighting Generator Partially Wound.

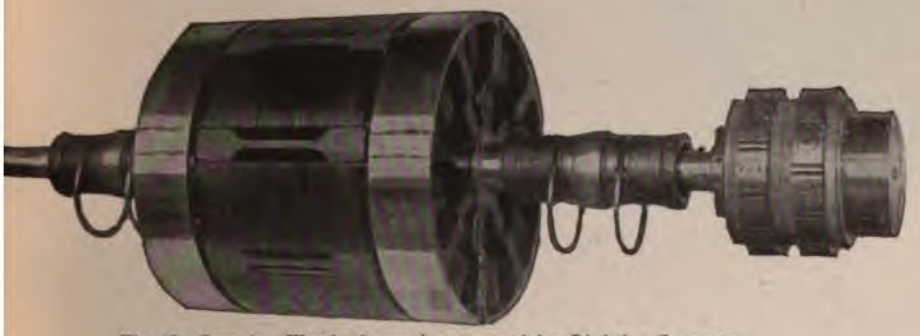


Fig. 65. Complete Westinghouse Armature of Arc Lighting Generator.

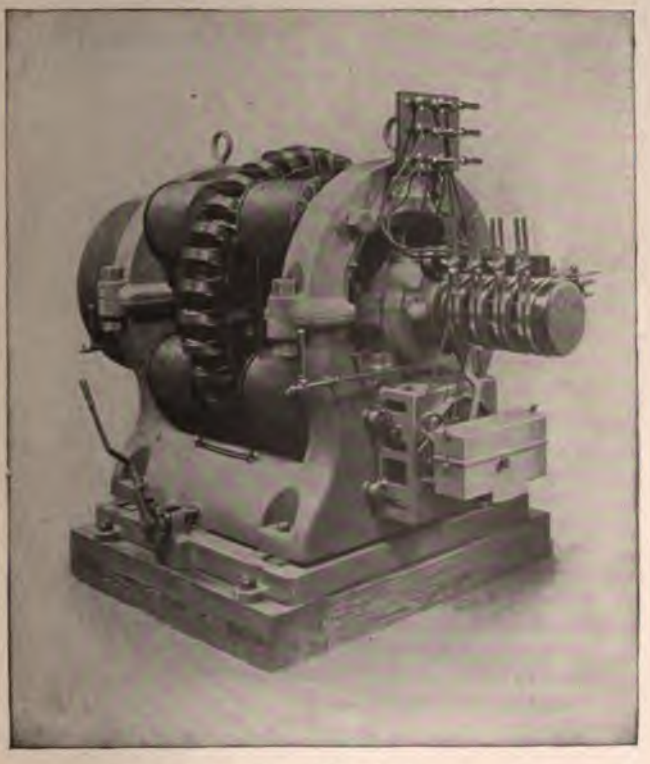


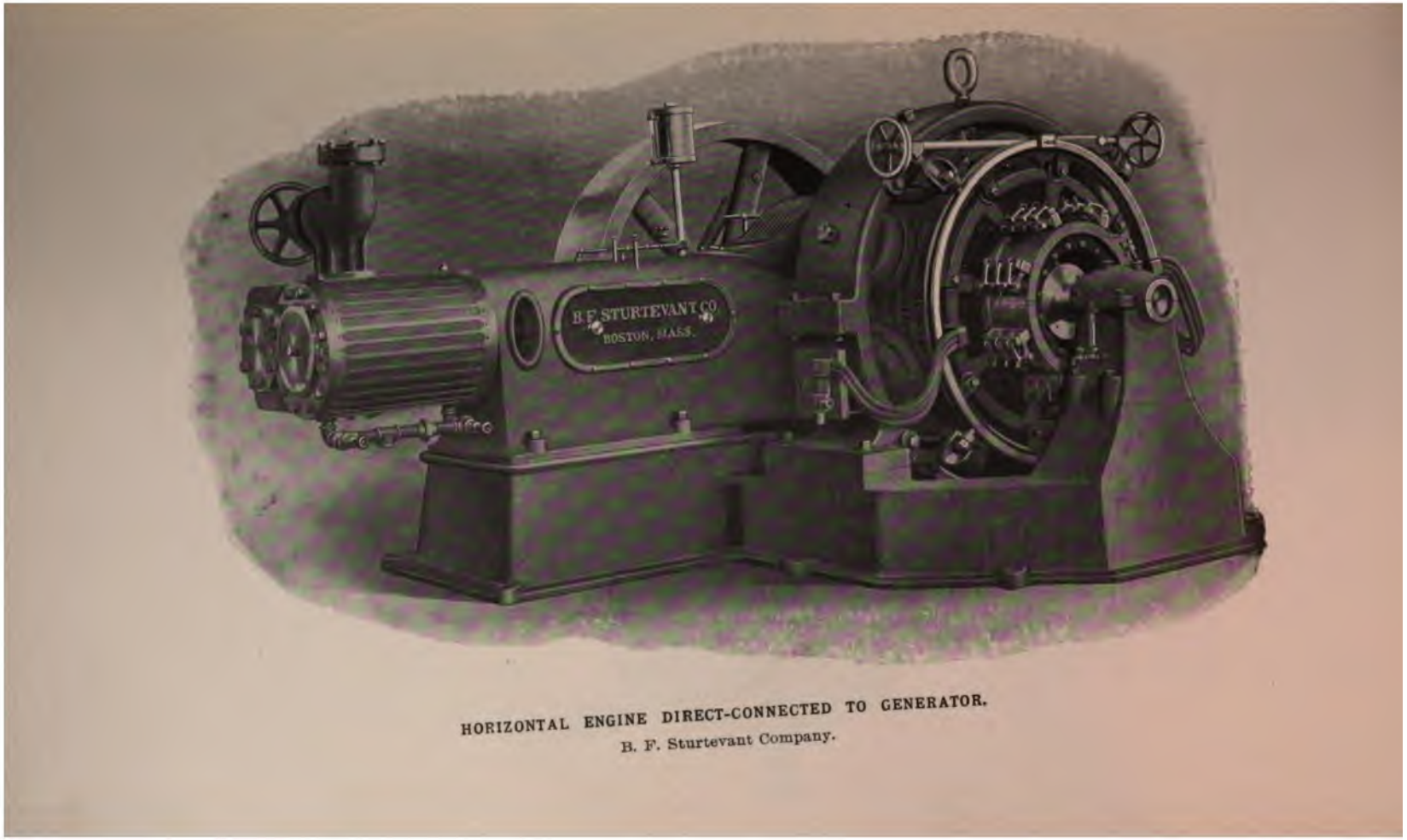
Fig.66. General Electric Arc Lighting Generator.

DIRECT CURRENT MOTORS.

Many characteristic features of the engine-type and dire driven direct current generators are now commonly followed designing direct current motors. Formerly the leading types

Fig. 67. Direct-Connected Crocker-Wheeler Motor in Testing Frame

motor were, generally speaking, of high speed and had to be belt to the machinery which they drove. Representative manufacture however, now favor the direct method of driving. The 2-p motor is giving way to the multipolar type, and the high spe



HORIZONTAL ENGINE DIRECT-CONNECTED TO GENERATOR.

B. F. Sturtevant Company.

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is being superseded by speeds of from 300 to 800 R. P. M. In some instances even lower speeds than 300 are used.

Slow-speed motors for direct driving are now commonly mounted upon the shafts of lathes, boring mills, drill presses, shapers, punching machinery, hydrostatic presses, laundry machinery, traveling cranes, pumps, printing presses, mine hoists and many other classes of machinery.

When a machine is driven by a direct-connected motor it may be placed in the most convenient position for operating, whereas

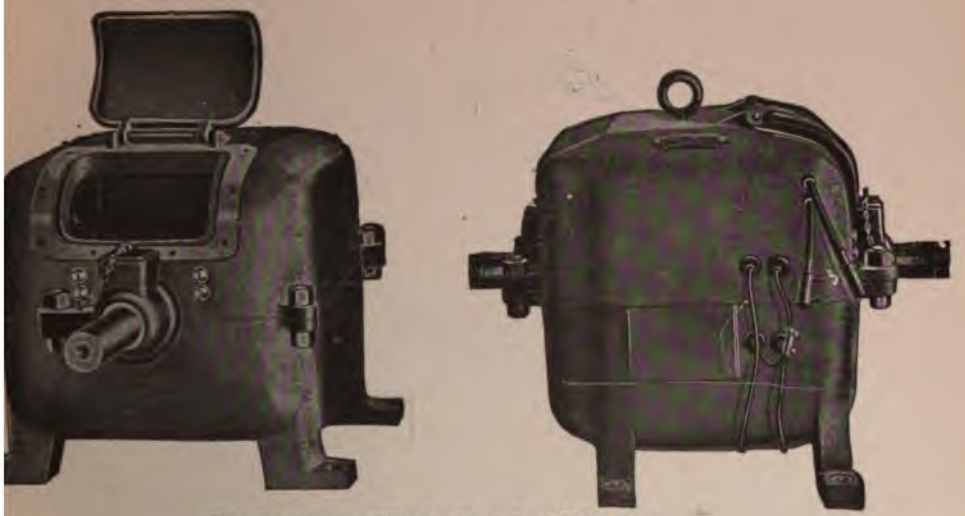


Fig. 68. Crocker-Wheeler Dust-Proof Mill Motor.

machinery driven by line shafting has to be placed in positions determined partly by the shafting. Shafting is entirely done away with in plants where all the machinery is direct driven by motors. Many prominent printing plants are now operated by motors direct connected to the presses, and this system of direct driving is being applied to a large percentage of the great mills, factories and steel works.

The absence of shafting and belting in a mill is a great advantage, as belts and shafts interfere with the lighting and ventilating of the premises and are dirty, noisy and cumbersome Moreover, in many plants a very large percentage of the total power is wasted in driving the shafting. In some plants having

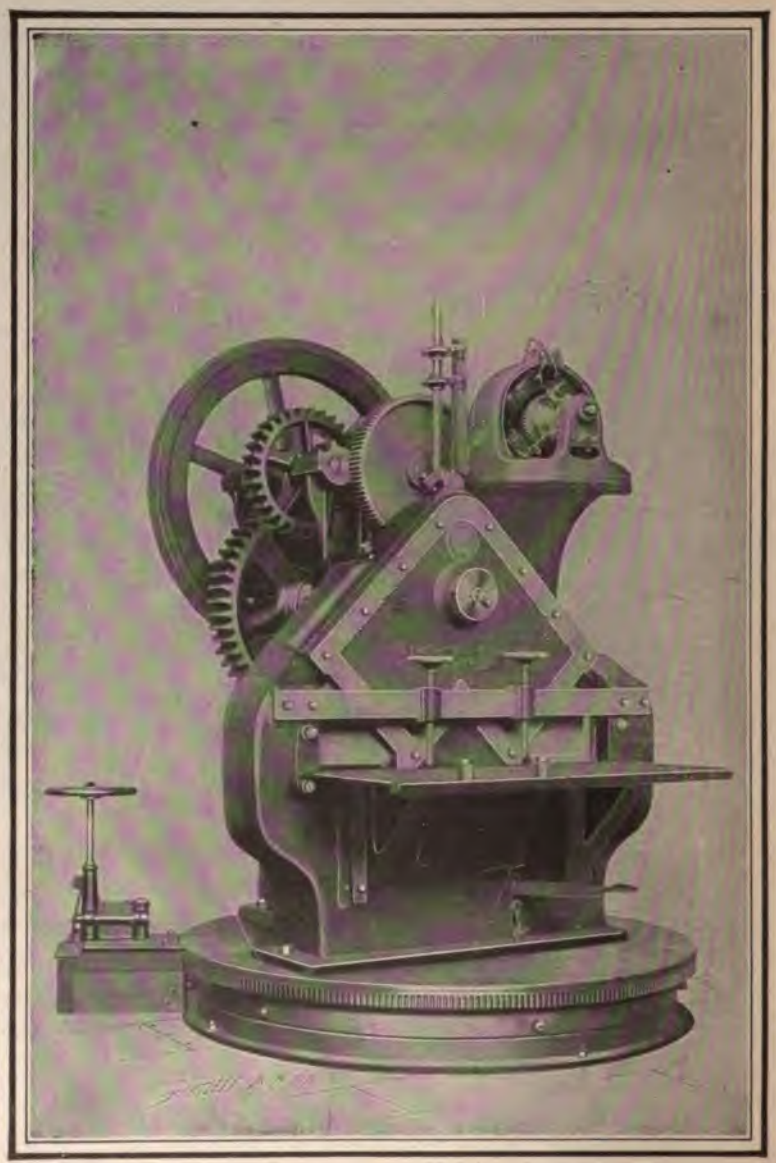


Fig. 69. Westinghouse Multipolar Motor Operating Shears.

an unusually great amount of belting it is said that 75% of the output of the driving engines is probably lost in the shafting, countershafting and belting, only about 25% being left for driving the machinery.

In plants driven by motors attached directly to the various machine tools there is a very great gain in cleanliness and in attractive working conditions. The control of the various machines is far better and the plant is operated with much less noise. Instead of having from 25 to 50% only of the output of the steam engines available for operating the machinery, with a well-built electric equipment over 75% of the total power is delivered at the shafts of the machine tools.

On the other hand, the cost of installing electric motors is at all times a considerable item, particularly where a large number of small motors are used. This expense is increased when multipolar slow-speed motors are used, as motors of slow-speed type are usually much more massive and expensive than the old-fashioned, compact, high-speed motors. So it follows that in equipping a large factory with slow-speed motors the cost is necessarily great. The interest on this extra cost (over the cost of a system of belting) often offsets the gain in efficiency — at least in part.

In equipping a plant with slow-speed direct-connected motors one must take into account the great economy in fuel, the better conditions of running and controlling the machinery, and the much increased working efficiency of the employees. These are the results that follow the electric equipment of a factory. When the first cost of electric apparatus is not absolutely prohibitive it is advisable to adopt the electric system of direct driving or else electric driving by means of short lines of shafting.

In many cases, however, the first cost of electric equipment makes it out of the question. In such cases for instance as where fuel is very cheap, efficiency in running is not so important as economy in the first cost of the plant.

The student should make a very careful study of the various representative types of slow-speed motors shown in this book, noting the various applications illustrated. He should also find out for himself the selling prices of such apparatus, and he may then decide whether the expense of the electric system is justified

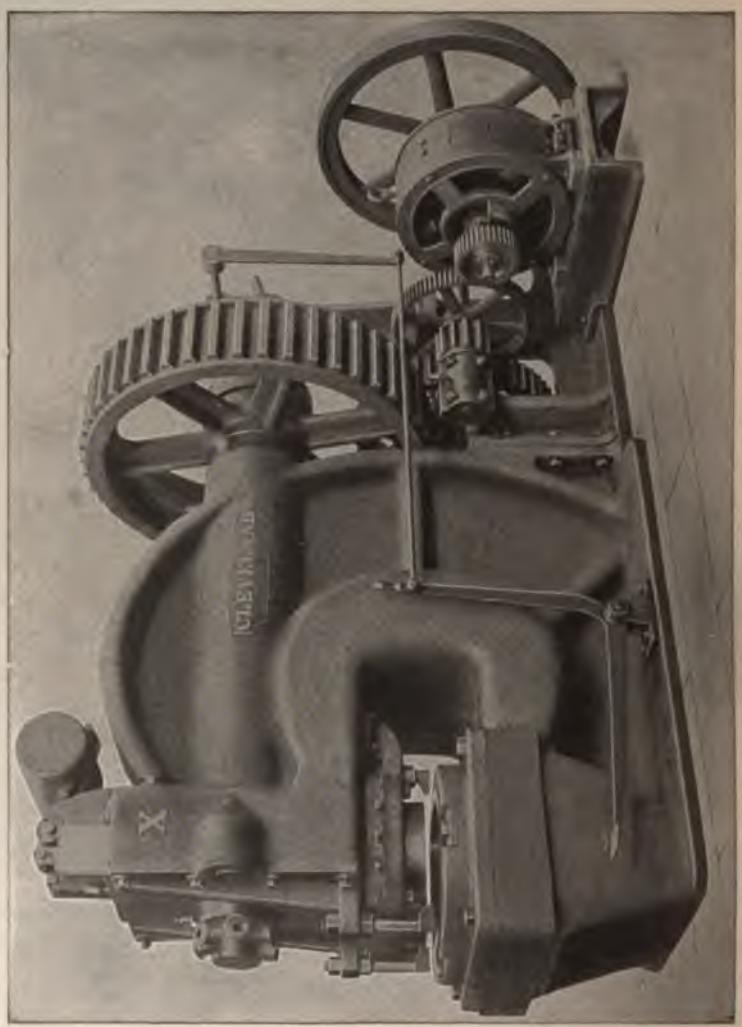


Fig. 70. Westinghouse Motor Operating Punch.

in any special case. The tendency of the times is unmistakably in favor of electric driving. The newer types of motor are as substantially built, as little likely to break down, and as easily regulated as first-class steam engines. The old, unventilated and high-speed motors on the other hand were generally delicate, subject to breakdowns, often wasteful of power, noisy, and not perfectly steady in operation.

A typical high grade modern motor for direct driving is

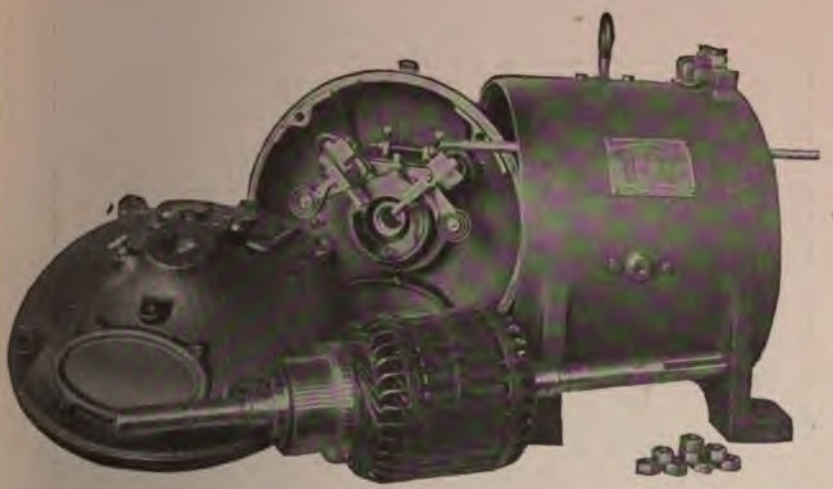


Fig. 71. Westinghouse Dust-Proof Motor.

shown in Fig. 67. This is made by the **Crocker-Wheeler Company** and follows in a general way the design of typical slow-speed direct connected generators. The motor has no shaft of its own, as it is intended to be keyed directly onto the shaft of the machine which it is to drive. It is built for various voltages and speeds, runs smoothly, and is well adapted to a variety of mill and factory applications.

The electric motor is now required for service in very diffi-

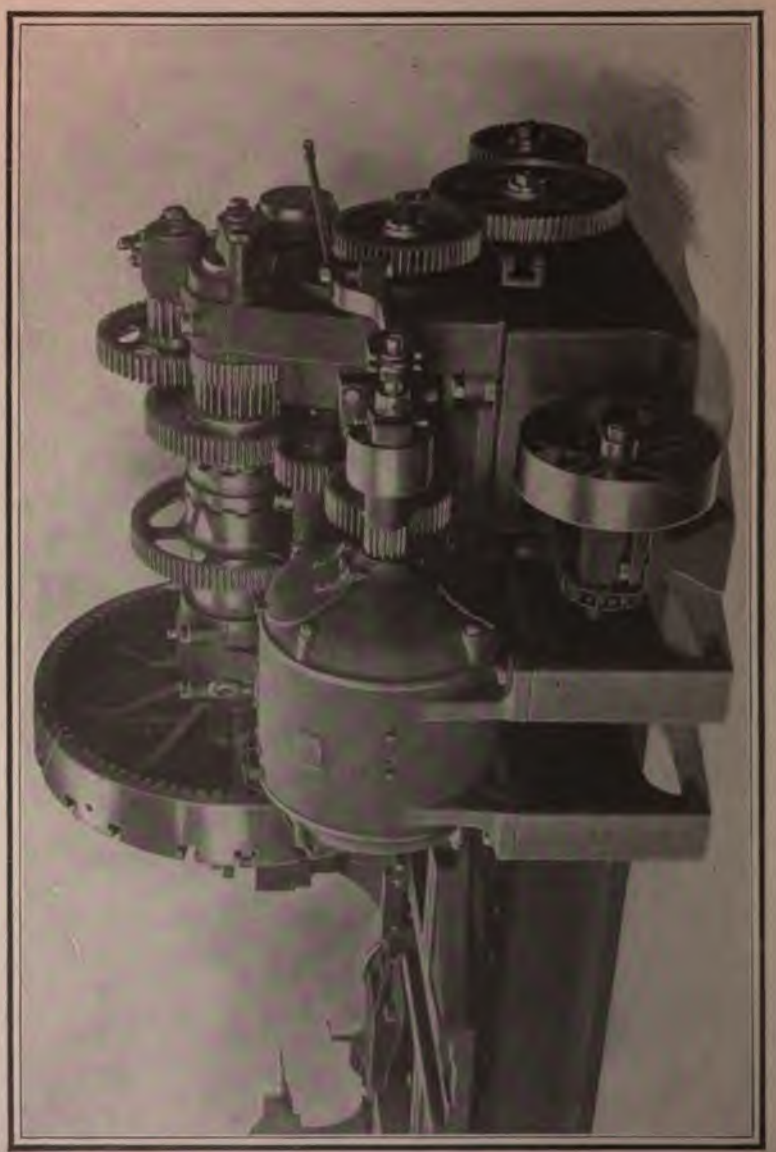


Fig 72 Westinghouse Dust-Proof Motor Operating Gun Lathe.

cult situations in which the earlier type of motor would speedily have been ruined. Thus in steel mills, flour mills, woodworking shops, boiler rooms, etc., etc., where the air is continually filled with fine particles, the motor must be of unusually substantial construction.

The motors for such service are often enclosed in a practically air-tight case of steel. Such motors, of course, are larger for a given output than open, ventilated motors, as a motor which is enclosed cannot be so well ventilated, and must, therefore, carry larger conductors in order to compensate for heat losses. But large conductors even when heated up might give a better efficiency than could be shown by a well-ventilated motor wound with too small wire.

Fig. 68 shows a Crocker-Wheeler dust-proof motor. In this motor the "iron-clad" armature is completely encased in a cast-steel box, forming the frame of the field. While such motors are not very well adapted for continuous running, they serve admirably for use in intermittent service. The interior of the machine may be reached through the air-tight lid seen in the left-hand figure.

The Crocker-Wheeler Company makes a variety of mill motors designed for connecting direct to the shaft of the machinery which they drive. At slow speeds they are designed to give a very heavy torque, being compound wound with a small shunt.

Slow-speed motors for a given weight of material have usually a smaller output of power than the high-speed types. This in no way means decreased electrical efficiency, but simply that the slow-speed motor (for a given horse-power rating) is heavier and larger than the high-speed type. On the other hand, the slow-speed type runs cool and has far better mechanical construction. Its efficiency is ordinarily very high, and it is much better adapted for long-continued heavy loads than the high-speed motor.

Fig. 69 shows a **Westinghouse** multipolar direct current motor operating a pair of shears for cutting heavy steel plates. Fig. 70 shows a Westinghouse multipolar direct current motor operating a punch.

Fig. 71 shows the Westinghouse dust-proof motor taken

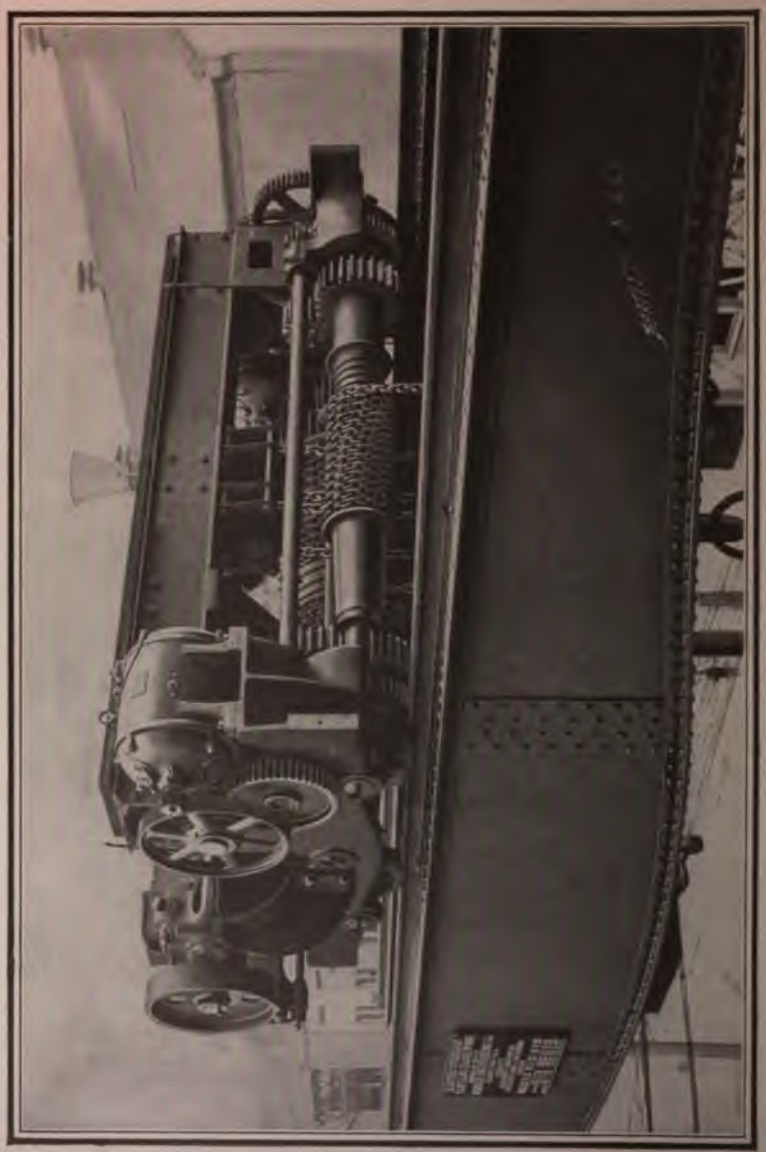


Fig. 78. Westinghouse Motors Operating Out-Door Crane.

apart. The armature, commutator and shaft are shown together; the brushes and brush-holder are seen attached to the interior of one of the lids of the motor case; the field poles are hidden by the frame of the motor. Fig. 72 shows the dust-proof motor operating a 50-inch gun lathe. Fig. 73 shows dust-proof motors mounted upon and operating an outdoor crane at Pittsburg, Pa.

Fig. 74 shows a multipolar motor manufactured by the **Bullock Electric Mfg. Co.**, and designed for driving mill and fac-

Fig. 74. Bullock Multipolar Motor.

tory machinery without belting. These motors are usually geared to the shaft of the machine tool which they operate.

The Bullock motor for work of this character is, as seen in Fig. 74, of a compact, strong design. It is made either of the dust-proof type shown in the figure or of the open, ventilated type. The enclosed or dust-proof type is useful in all cases where the motor is exposed to iron filings or quantities of dust, but being less completely ventilated than the open type a somewhat larger size for a given grade of work may be required. The enclosed motor works admirably however when the load is intermittent, as the motor has ample opportunity to cool in the intervals of work. Figs. 75, 76, 77 and 78, show applications of Bullock motors to machine tools of various kinds.

Fig. 79 shows a Bullock direct current motor installed underneath a large Hoe sextuple press with color attachment. The motor is direct connected to the press, and its speed is controlled by the movement of the hand-wheel. The motor may be started slowly and then run through a succession of increasing speeds up to full speed. Fig. 80 shows a Bullock motor connected to a Cottrell perfecting magazine press, and Fig. 81 shows these motors connected to a number of magazine presses in the pressroom of *Munsey's Magazine.*

Fig. 82 shows the **Lundell** 6-pole single field coil medium-speed motor manufactured by the Sprague Electric Co. It is

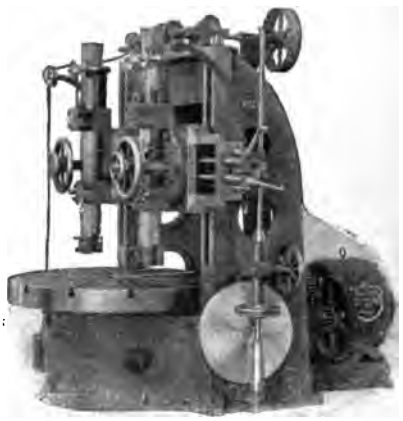


Fig. 75. Bullock Motor Application.

made in sizes of from 10 to 60 H. P. and runs at speeds of from 600 to 950 R. P. M. The field frame is cast in two pieces, the pole pieces being cast together with the yoke. The bearings are self-aligning and self-oiling, and are supported by brackets secured to the pole frame of the motor. These motors are semi-enclosed, the commutator being exposed and accessible for inspection.

A feature of these machines is the division of the field frame into two symmetrically placed halves bolted together in a vertical plane. The bearing pedestals are removable, and the two halves of the field frame may be moved out *sideways* for dismembering the machine. These motors are ordinarily wound for 115, 230 and 500 volts but are also wound for any special voltage.

Fig. 83 shows the Lundell round-type motor with self-aligning and self-oiling bearings, with side doors fitted to the openings in the frame on the commutator end, making the motor wholly enclosed if so desired. Motors of the same class are also made for slow speed, specially adapted for driving printing-presses and similar machinery.

High and low speed direct current motors are manufactured by the **Triumph Company** as follows: Fig. 84 shows the Triumph slow-speed direct-connected motor, and Fig. 85 shows

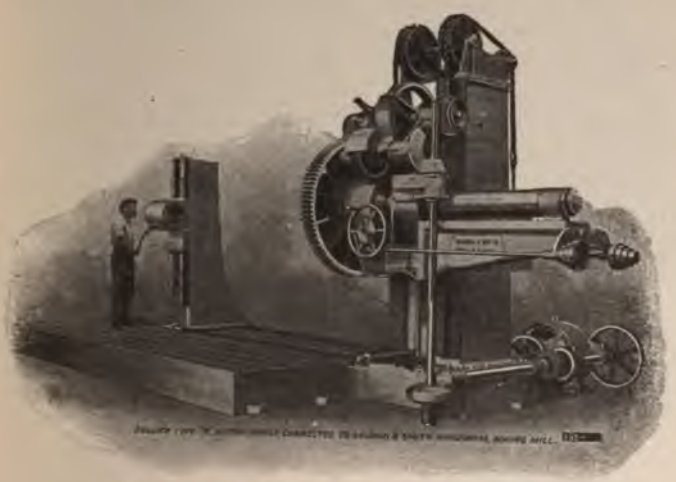


Fig. 78. Bullock Motor Operating Boring Mill.

several important applications of the Triumph motor. A small Triumph motor, intended for use in places where the motor is exposed to dust and dirt, is seen in Fig. 86. It is encased in a cast-iron frame, but the commutator may be reached by removing the doors. These doors, if desired, are perforated with numbers of holes provided for ventilation, a fine screening being fastened inside the door to prevent the ingress of dirt. This motor may be bolted to floor, wall or ceiling.

Triumph machines are characterized by field frames of soft cast iron and laminated pole pieces built up of sheet iron and cast welded into the frame. The pole pieces are fitted with cast-iron

"shoes," the horns being shaped to give a suitable magnetic field. Field frames are divided vertically in some instances and horizontally in others. The field coils are separately wound on forms and slipped into position upon the pole pieces. The armatures

Fig. 77. Bullock Motor Operating Lathe.

are iron-clad with laminated cores and are of the toothed type. The slots are insulated by troughs of fullerboard, mica and paper. Coils are held in position by wooden wedges without binding

Fig. 78. Bullock Motor Operating Lathe.

wires. The lower half of the field frame and the pedestals are made in one casting, an arrangement which gives accurate centering. Armatures are bar wound and so constructed as to allow free circulation of air.

Fig. 87 shows the **Western** enclosed motor suspended from the ceiling and arranged for transmission of power by belt and pulley. The bearings which support the countershaft are secured to the motor by brackets bolted to the frame of the motor. By shifting the position of these brackets the countershaft may be swung completely around, so as to hang directly beneath the motor or at the extreme right-hand side. The large gear-wheel will, of course, remain in mesh with the pinion carried by the

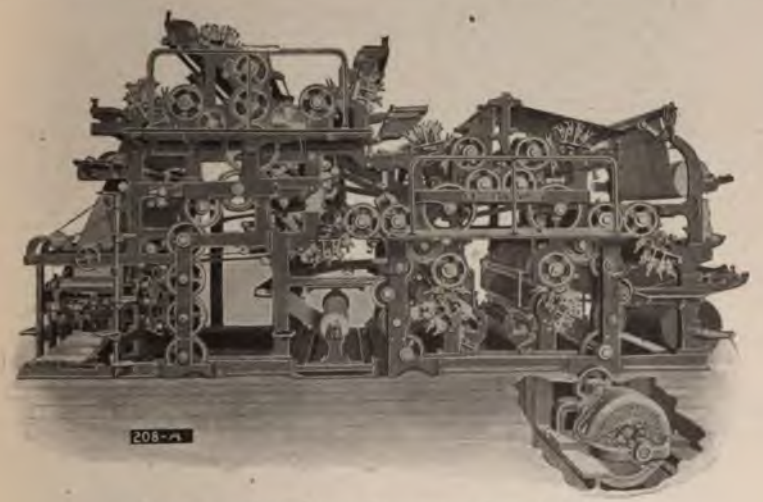


Fig. 79. Bullock Motor Operating Printing Press.

armature, whatever position the countershaft may occupy. This appears to be a very valuable arrangement, giving the motor unusually extended range of adjustment.

Fig. 88 shows the **Fort Wayne 6-pole** belted motor. The frame and right-hand bearing are cast in one piece, of the best quality of iron. The pedestal upon the pulley end of the shaft may be unbolted and the armature may then be slipped off for repairs. The construction shown gives very great rigidity. These motors run from 300 to 600 R. P. M.

Fig. 89 shows the **Commercial Electric Company's** "iron-clad" moderate-speed motor. These machines are designed to give the best possible protection to the motor windings when the machine is exposed to the weather or to a dust-loaded atmosphere.

The casing has large doors or panels which may be opened for inspecting the interior.

Commercial motors are also made to hang from the ceiling (See Fig. 90.) This motor runs on slide rods, by means of which the belt may be adjusted.

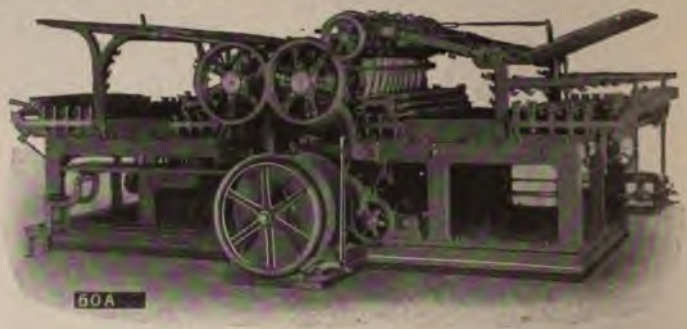


Fig. 80. Bullock Motor Operating Printing Press.

Fig. 91 shows a large-size Commercial multipolar motor for belt driving.

C & C motors are shown as follows. The special C & C motor which may be wound for a variety of speeds and capacities

Fig. 81. Bullock Motors in a Magazine Press Room.

is seen in Fig. 92. If the motor is desired for exceptionally slow speed, it is wound with two commutators and double arma-

ture windings. Fig. 93 shows an interesting type of C & C motor intended to run with its shaft in a vertical position, and Fig. 94 shows an open type of C & C motor intended for horizontal running.

The C & C Co. and the Westinghouse Co. recommend the grouping of machine tools together, a single electric motor being

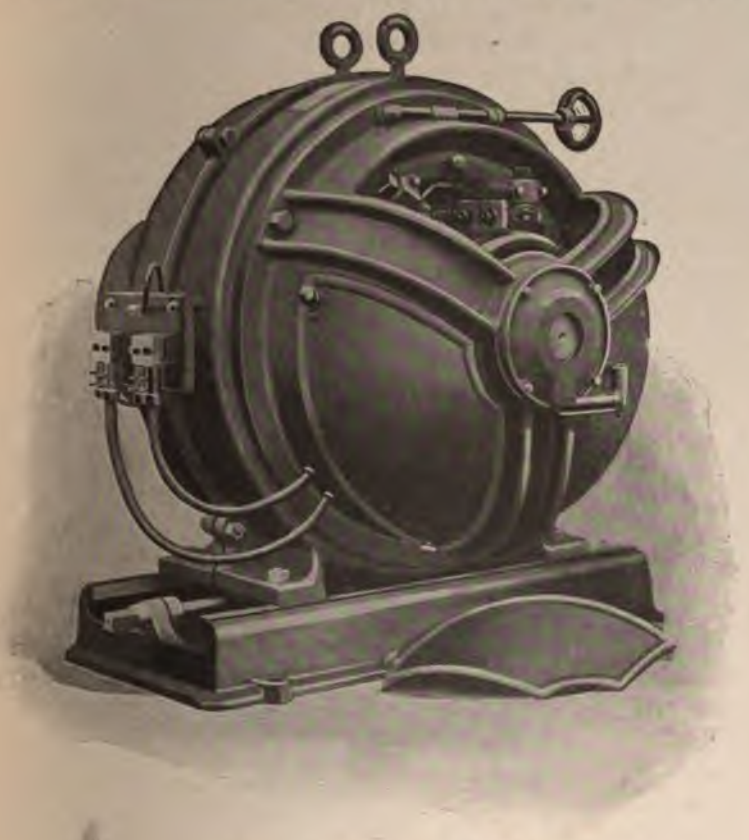


Fig. 82. Lundell Six-Pole Motor.

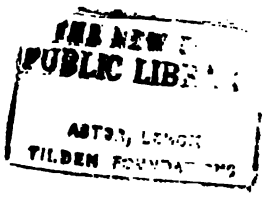
used to drive the group through a short shaft. This avoids the expense of individual motors and does away with long lines of shafting. Any machine which runs for a large part of the time at light load cannot be run economically by an individual motor, as the motor would be running during a large part of the time at so light a load as to show poor efficiency. By grouping several

machine tools together and running them by a single motor it is possible to obtain a much more uniform load for the motor, as the chances are that one tool might be running light while another was heavily loaded, and so on.

The Northern Electrical Manufacturing Company manufactures an excellent line of motors for direct and indirect driving. Types of these motors are illustrated in Figs. 95, 96 and 97. The motors shown in Figs. 96 and 97 are of the enclosed type, but in Fig. 96 may be seen a ventilated shield or cover for the commutator and brushes through which a supply of air circulates. Motors designed for direct connection, as we have said, are highly desirable in the larger sizes, because of their superior efficiency. In the very small sizes, the direct connected type is also extremely convenient because of its compactness and the absence of noisy gear-wheels.

Fig. 95 shows a particularly attractive design for direct connection.

Fig. 83. Lundell Motor with Covers.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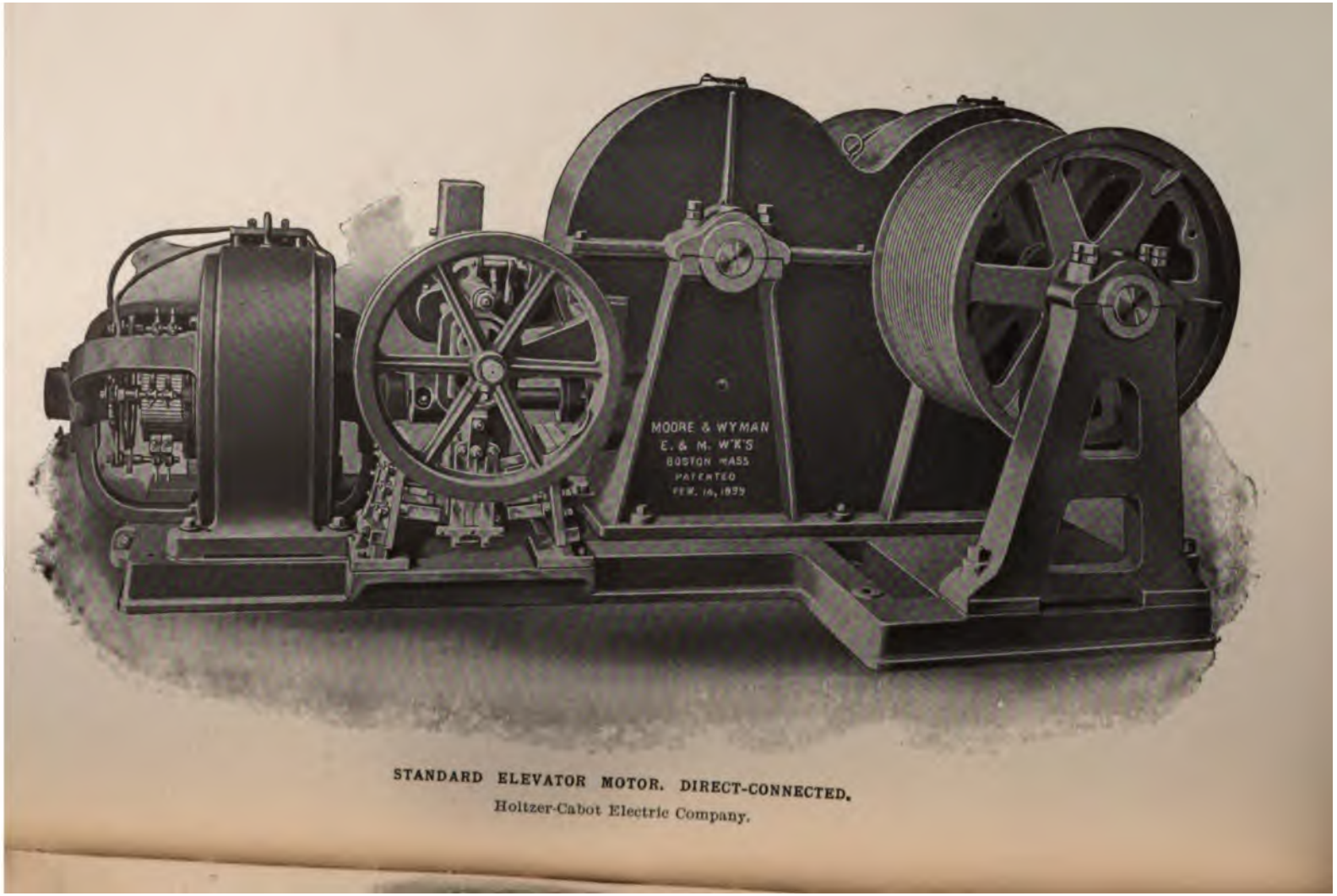


STANDARD ELEVATOR MOTOR. DIRECT-CONNECTED.

Holtzer-Cabot Electric Company.

RAILWAY MOTORS.

The modern trolley car is usually of very heavy construction, carries heavy loads and must make long continuous runs at high speed. The motors occupy a cramped position under the body of the car, are exposed to the hardest conditions from dirt and water,

Fig. 84. Triumph Motor.

and ventilation is greatly interfered with by the requirements of compact design. Yet the motor must run fairly cool at ordinary loads and must stand very heavy overloads for a short time.

Modern railway motors meet these difficult conditions admirably; a complete breakdown of the insulation is very rare and mechanical injury is well guarded against. Whereas a few years

ago a 25 H. P. car motor was considered large, the recent designs run up to 150 H. P. In fact there are now in use electric car motors running up to 250 H. P., four of these being used upon a single large car on one of the European electrical roads.

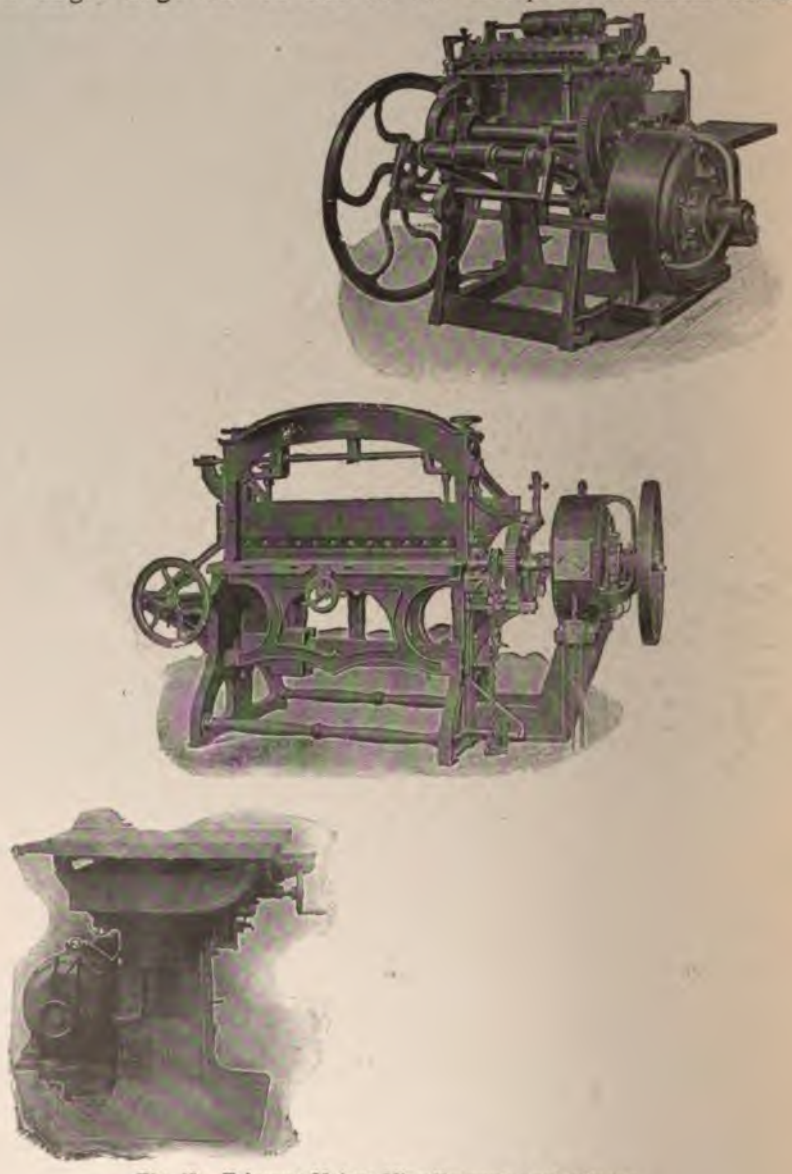


Fig. 85. Triumph Motor; Miscellaneous Applications.

These motors are, however, of the "induction" type, and are discussed in "Alternating Current Machinery." We believe that 150 H. P. is about the maximum size of direct current car motor thus far introduced into regular service.

Fig. 98 shows a **General Electric** (GE-73) railway motor. The axle runs through bearings bolted to the main casing of the motor; the gears are enclosed as shown at the right-hand end of the cut; the motor frame is a single casting, carrying four poles attached to its inner face by bolts. This construction is widely approved of, as it gives a compact, strong motor. In order to remove the armature it is necessary to unbolt the armature bear-

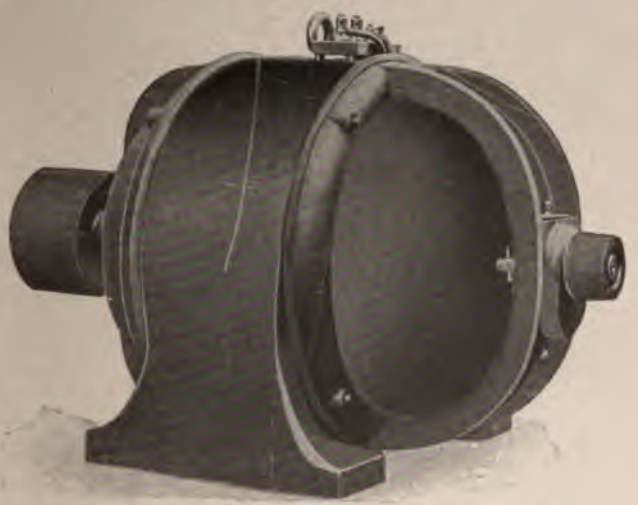


Fig. 86. Small Triumph Motor.

ings, after which the armature may be slid out endwise. This is a difficult matter and necessitates removing the motor from the truck. Repairs, however, are rarely necessary with a motor of such strong construction.

Fig. 99 gives a rear view of the same motor. The various leads are seen introduced into the casing, all connections being made inside. Access to the interior is obtained by means of the various lids and handholes which the motor carries. The pinion seen in this illustration is carried upon the armature shaft, the gear-wheel with which it engages being carried upon the car axle.

Such a motor is practically dust and moisture proof. When running under suitable conditions the lids are left open for ventilation, although the motor is designed to run without excessive heating in ordinary use. The motor shown has a rating of 75 H. P., based upon a rise of 75° C. during one hour's run at full load.

Fig. 100 shows the **Westinghouse** No. 56 railway motor which runs up to 100 H. P. It runs on interurban lines where

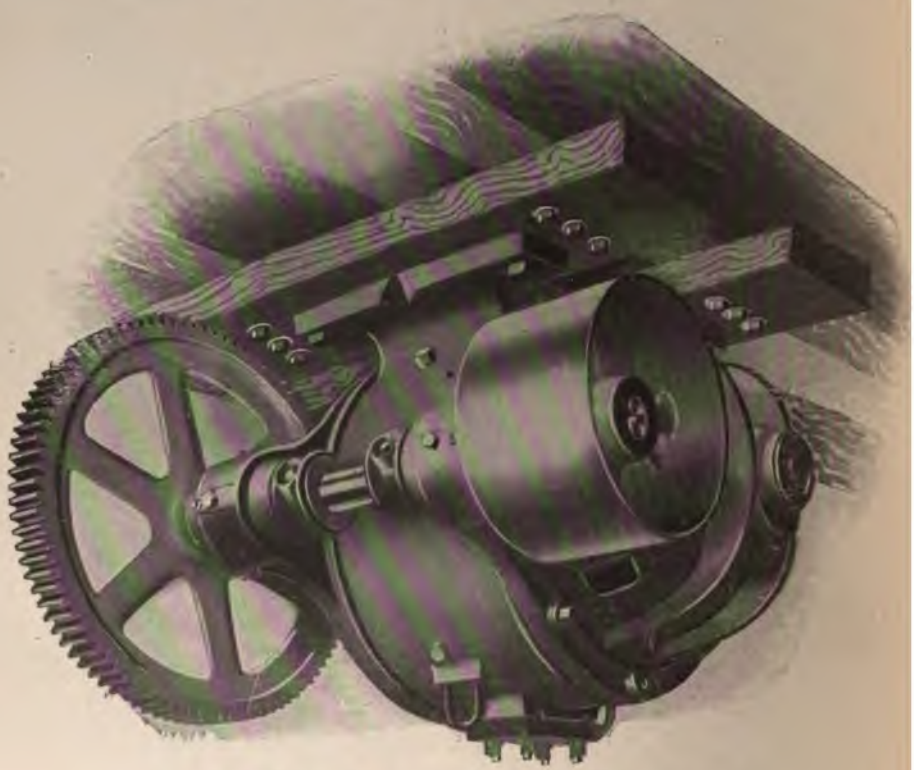


Fig. 87. Western Enclosed Motor Suspended from Ceiling.

it must operate continuously for long periods. The motor is enclosed in a steel casing, but although ventilation is restricted the motor runs comparatively cool. Fig. 101 shows the motor opened up by means of hinges cast into the casing, the main casing being in two sections. In this illustration the pole pieces are seen surrounded by the field coils, and an excellent view of the armature windings, commutator, bearings and pinion is obtained.

Motors of this design are almost perfectly dust and moisture proof, but will not endure complete submergence in water.

In railway motors there must be as stated before a considerable overload capacity, to meet the requirements of starting under heavy load, and for climbing grades, etc. It is first-class practice, if a motor has a continuous capacity of 50 amperes, to provide for a current of 100 amperes for 15 minutes, or a load

Fig. 88. Fort Wayne 6-pole Belted Motor.

of 140 amperes for 5 minutes, or 60 amperes for one hour and twenty-five minutes. This is the specification of the Westinghouse No. 56 motor, based upon a maximum temperature rise of 75° C.

Fig. 102 shows a Westinghouse No. 49 motor which is designed for medium-speed city and suburban service. It carries

four laminated pole pieces cast welded into the yoke or casing. The two halves of this casing are hinged together and may be opened up for inspecting the interior or removing the armature. Such motors may be repaired in position upon the car. The armature is slotted, carries ventilating ducts and is wound with light binding wires.

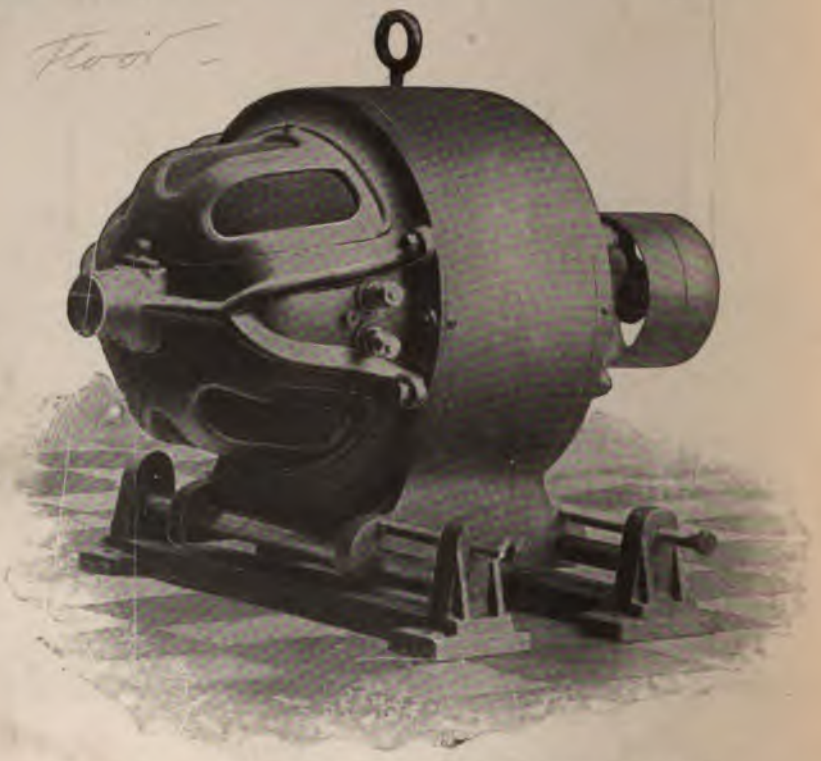


Fig. 89. Commercial Electric Co.'s "Iron-Clad" Moderate-Speed Motor.

ELECTRIC LOCOMOTIVES.

Electric power is now applied extensively to mining operations, for hauling the ore cars, operating the pumps, and in fact running all the machinery of the plant for mining and milling ores. The development of mining properties in which low grades of ore are handled has made it necessary to economize in the running expenses of the plant in all possible ways, and in substitut-

ing electric power for mules in hauling cars a very surprising saving is effected.

Fig. 103 shows the **General Electric** mine locomotive operated from an overhead trolley, and Fig. 104 shows end views of similar locomotives.

In most mine passages there is very little head-room and it will be seen in the figure that the locomotive is of unusually low design. In fact, the maximum height of such a locomotive (not including the trolley pole) is in many cases not more than 36 inches, and rarely exceeds 50 inches.

The locomotive is controlled from the operating platform at

Fig. 90. Commercial Electric Co.'s Motor Suspended from Ceiling.

one end, where the operator sits. The equipment of the locomotive is similar to that of a trolley car. In addition to the motors there are the usual controller, rheostat, etc.

Mine locomotives are generally designed to run at speeds of from 6 to 8 miles per hour. As the track gage is in most mines extremely narrow (usually about three feet), and as the locomotive is of very limited height, it is evident that there can be but little room for the motors and their suspension gear. By skilful designing, however, it has been found possible to construct mine

locomotives in which the essential features of first-class street railway power equipment are preserved. Such locomotives run cool, are easily controlled, and highly efficient in operation.

Fig. 105 shows the **Bullock** electric locomotive and crane car for use on surface lines. It is equipped as a locomotive, capable

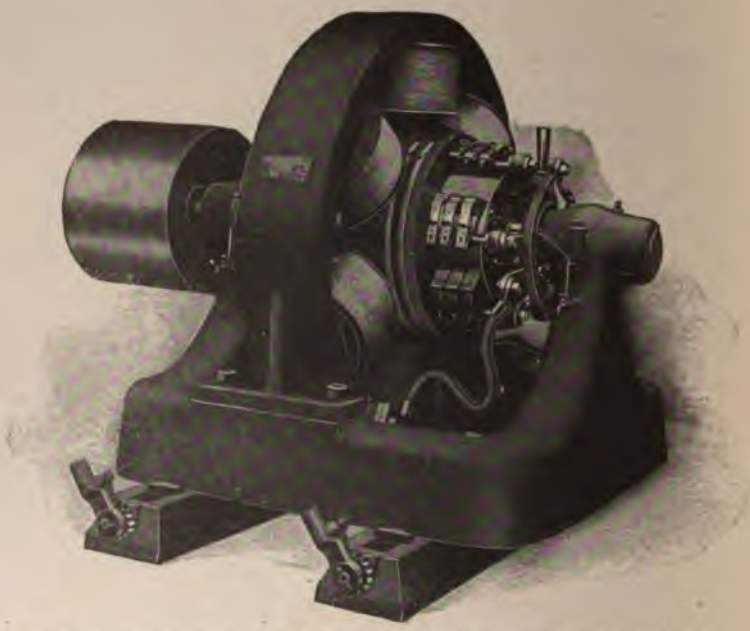


Fig. 91. Commercial Multipolar Motor for Belt Driving. (Large Size.)

of handling eight loaded freight cars on a level track. It is propelled by two motors, one on each axle, wound for any desired voltage. The illustration shows two trolley poles, with trolleys running on two wires, thus avoiding the necessity of grounding the circuit. This practice is common where the electric locomotive is used in connection with factories, the circuits of which it would be undesirable to ground.

The locomotive is of heavy construction, the extra weight being useful as a counterbalance for the crane. The wheel base is 9 feet long, and 33-inch railroad car wheels are used.

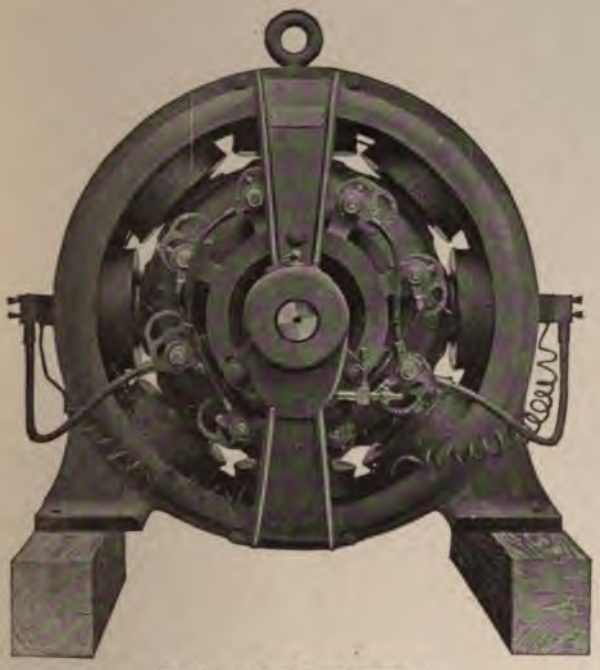


Fig. 92. C & C Special Motor.

Fig. 93. C & C Motor run with Shaft in Vertical Position.

Fig. 94. Open Type C & C Motor for Horizontal Running.

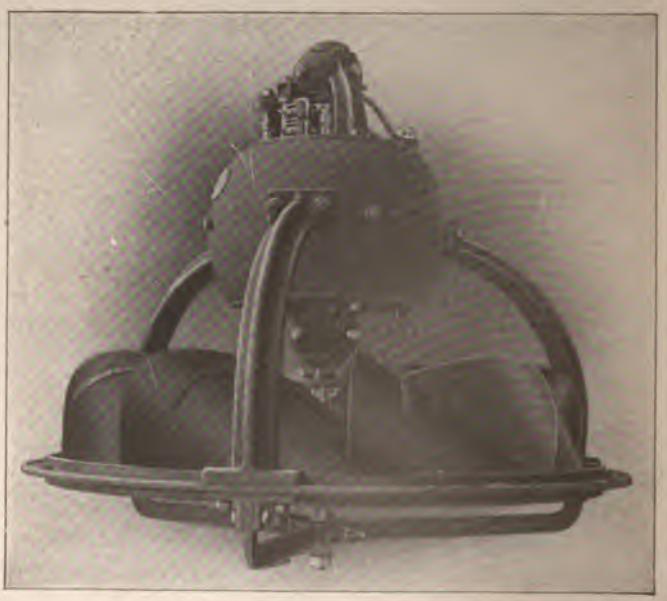


Fig. 95. Northern Motor Driving Ventilating Fan.

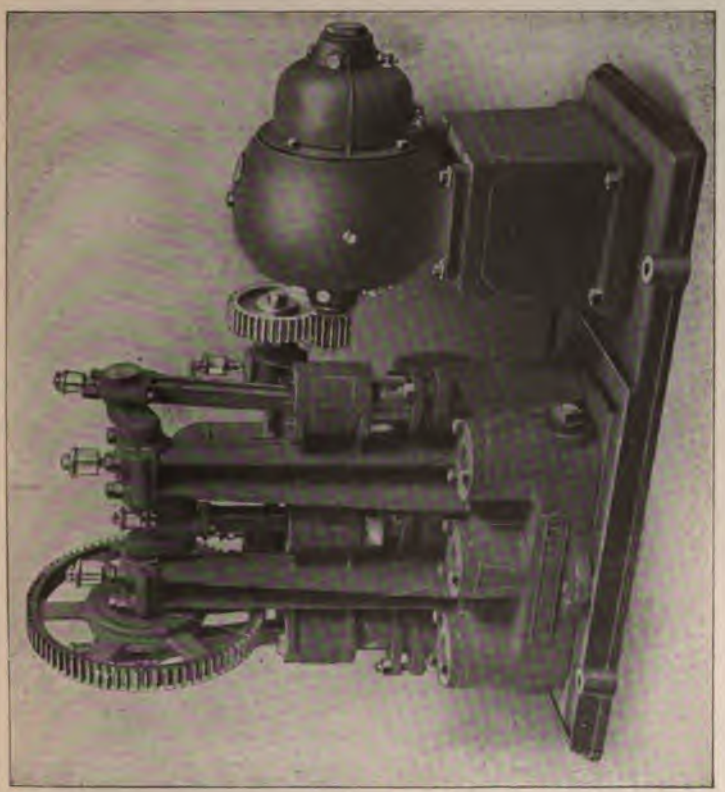


Fig. 97. Northern Motor Operating Triplex Pump.

Fig. 98. Northern Enclosed Motor with Vertical Shaft.

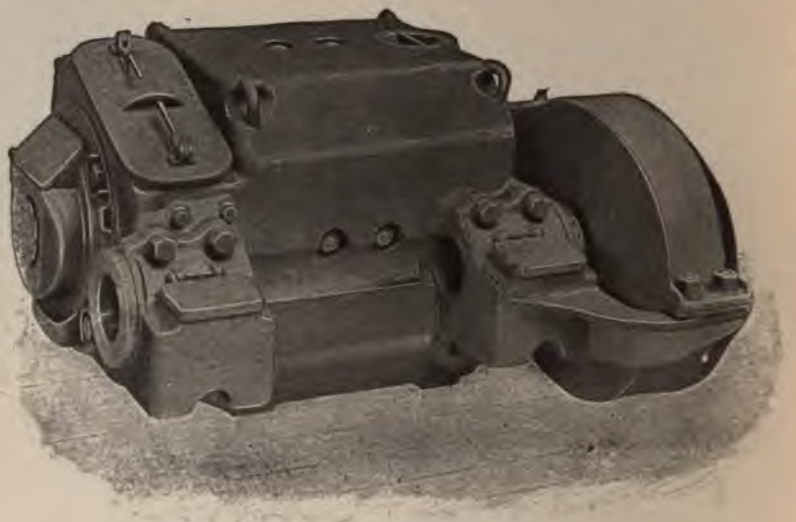


Fig. 98. General Electric Railway Motor.

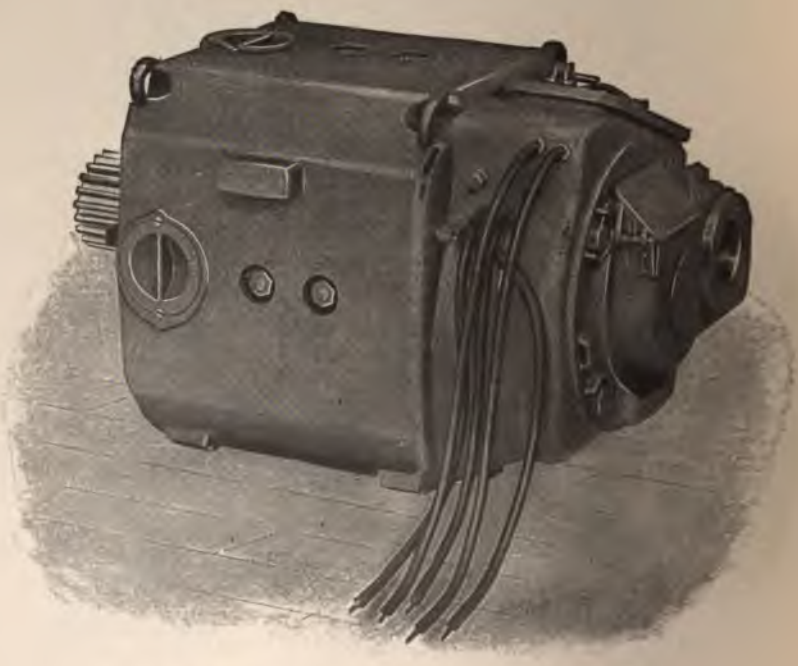


Fig. 99. General Electric Railway Motor, Rear View.

Fig. 100. Westinghouse Railway Motor.

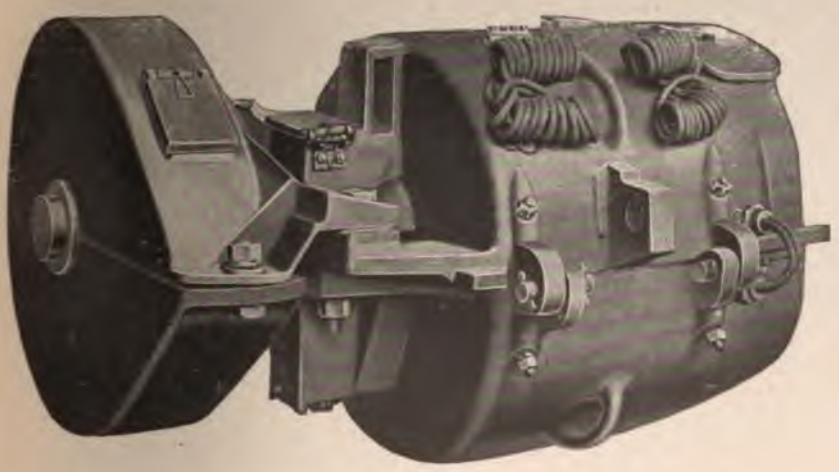


Fig. 102. Westinghouse Medium-Speed Railway Motor.

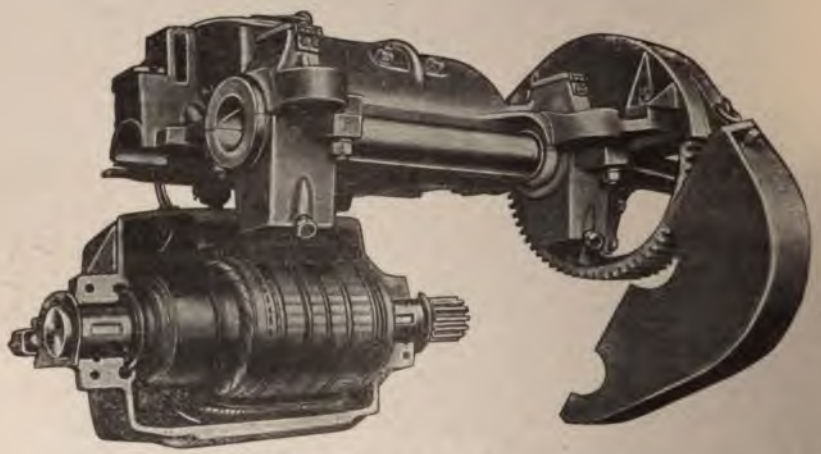


Fig. 101. Westinghouse Motor, Open.

Fig. 103. General Electric Mine Locomotive.

Fig. 104. General Electric Mine Locomotives.

Fig. 105. Bullock Electric Locomotive and Crane Car.

The above are modern American types of generators and motors for miscellaneous direct current work. The reader should bear in mind that the types here shown are representative, and are intended merely to give a general idea of contemporary practice. There are very few classes of mechanical work in which special motors are not now constructed. The number of these is accordingly very large, and it would be impossible in a book of this character to describe all of the special designs of motor and generator which are now on the market. Two most important classes of work are elevator and automobile service.

The automobile motor is in effect a miniature railway motor, of the enclosed type, and operated from a battery of 40 or 44 storage cells. It ranges in size up to 6 H. P., as made by the foremost manufacturers, and the larger automobiles frequently carry two such motors, one for each of the two rear wheels. Occasionally motors are used upon the front wheels.

ELECTRICALLY OPERATED GATE VALVE.
With Direct-Current Motor.
Chapman Valve Manufacturing Co.

Motors of this class are as yet too new to show standard practice, although a number of satisfactory makes are now in practical use. The next few years will probably show great advance in this line of work.

The electric elevator motor is now in very extensive use both for operating elevators through rope driving gear and also

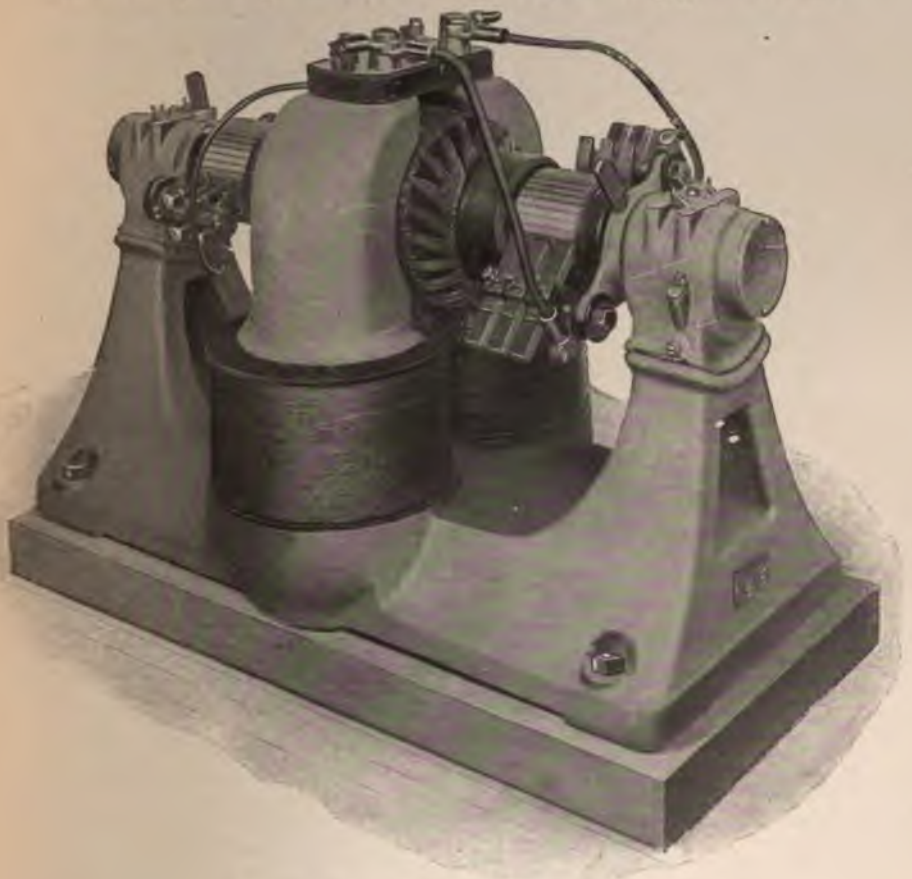


Fig. 106. Western Electric Co.'s Dynamotor.

for pumping water for hydraulic elevator machinery. Elevator motors are of the most substantial construction and are equipped with controllers having a large range of speed adjustment. Crocker-Wheeler elevator motors are supplied with an automatic band brake, which appears to be a highly valuable

feature. Elevator motors must, of course, be self-starting under heavy loads, and must be reversible.

As it is impossible to treat of all these classes of motors in a brief discussion, we have confined our attention mainly to the larger sizes and the more important applications of electric apparatus. In fact, it is only in the larger sizes that modern practice has developed standard types such as are here shown. The smaller machines, whether for general or special applications, are made in almost limitless varieties of shape and size.

MOTOR-GENERATORS AND DYNAMOTORS.

In many electric plants for power and lighting an electric motor is seen driving a generator either belted or direct connected to it. In such cases the motor takes the place of a steam engine, the operation of the generator being very much like that of similar machines driven in the usual manner. The purpose of this arrangement is usually to obtain from the generator so driven an output of electricity of different voltage from the main supply of the station. Thus a station supplying a trolley line at 500 volts may require a small supply of electricity for house-lighting at 110 volts. In instances like this a motor operating from the 500-volt circuit might be employed to drive a generator designed for supplying current at 110 volts. Such a combination of motor and generator is clumsy, and it is now customary to use for this service a combination machine known as a motor-generator, consisting of a motor and a generator running on the same shaft and having a common bedplate. A further modification of this design is known as the dynamotor. In the dynamotor there is but one armature and one field magnet. The armature is wound for the voltage supplied by the station, in the case cited above 500 volts, and together with the field magnet constitutes a motor operating like any simple direct current motor. The commutator for this motor winding is built upon one end of the armature shaft in the usual manner. The armature furthermore carries a separate set of windings, the terminals of which are brought out to a commutator upon the end of the shaft opposite to that carrying the motor-commutator. This second set of windings, acting under the influence of the field magnet and revolving with the motor

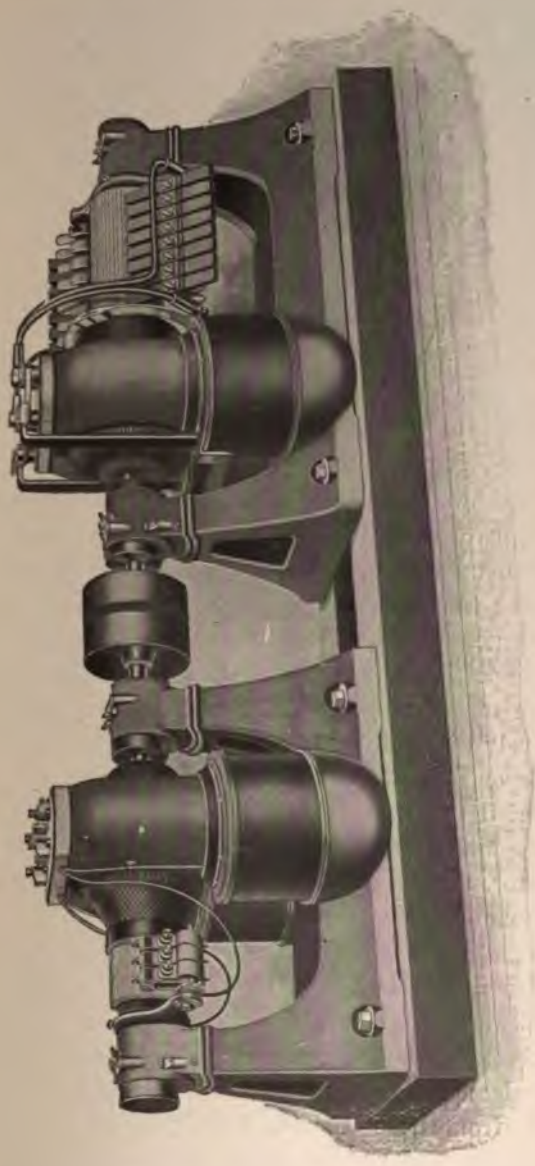


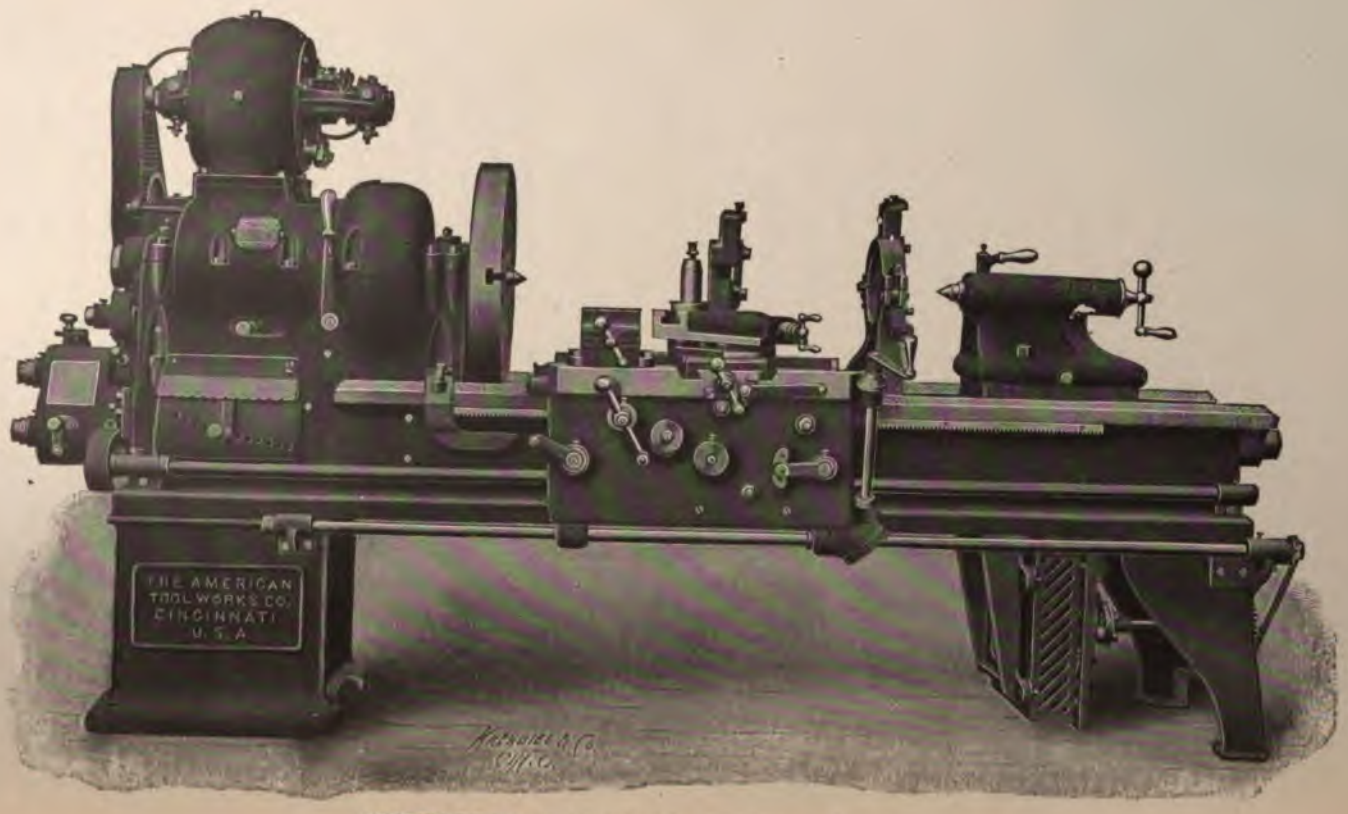
Fig. 107. Western Electric Co.'s Twin Motor-Generator.

windings, gives out a current of (in the case cited) 110 volts.

The dynamotor manufactured by the **Western Electric Co.** is shown in Fig. 106. A machine of this class is cheaper, more compact and of less weight than the motor-generator, and is also slightly more efficient. The dynamotor, however, has this disadvantage, that the secondary voltage — that is, the voltage on the generator side of the machine — cannot be varied to any extent except by introducing into one or the other of the circuits a certain amount of dead resistance. Also the generator side of the dynamotor will not have a constantly maintained voltage, owing to the resistance of the armature, and the machine cannot be wound to compensate for this change of E. M. F. On the other hand, the dynamotor will carry heavier overloads than the motor-generator.

Fig. 107 shows the Western Electric Co.'s motor-generator, or as this company styles it, the "Twin Motor-Generator." This machine has an advantage over the dynamotor inasmuch as it can be compounded to maintain a voltage on the generator side that will be constant, or, if required, to give a generator voltage that will rise in proportion to the load. In the twin motor-generator, moreover, the motor and generator circuits are insulated much more effectively than in the case of the dynamotor, in which the insulation depends upon wrappings between the two armature windings carried upon the same core. It is evident that there is very little essential difference between the dynamotor and the motor-generator. Some manufacturers show a preference for one design, and some for the other.

Boosters. A machine of the general class of dynamotors and motor-generators is the booster. It is in effect a motor driven usually from an electric light circuit and driving a separate generator mounted upon the same shaft. The voltage of such an electric light line usually falls off considerably at points distant from the station, and the purpose of the booster is to raise the voltage of the line up to standard at points where it shows such a falling off. Accordingly the generator portion of the machine is connected with the electric light circuit in such a way that its voltage (which is sufficient to compensate for the amount lost by the line) is added to the E. M. F. of the circuit



MOTOR-DRIVEN AMERICAN ENGINE LATHE.

DIRECT CURRENT MOTORS.

GENERAL DISCUSSION.

It has been shown that by means of a **generator** mechanical energy is converted into the electrical form of energy. An electric **motor** is the reverse of this, that is, it converts electrical energy into the mechanical form of energy.

Fundamental Principle. We have learned that when a conductor which forms part of a circuit moves so as to cut lines of magnetic force, a current passes in the conductor, this being the principle of the generator. On the other hand, if a current of electricity passes through a conductor at right angles to lines of magnetic force, the conductor tends to move so as to cut them. This will be made clear by considering Fig. 1. The dots repre-

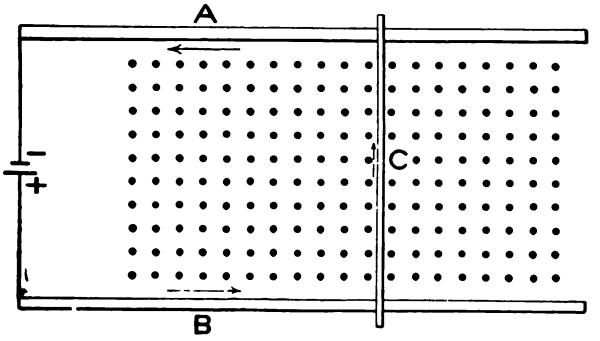


Fig. 1.

sent lines of magnetic force, their direction being upwards through the paper. *C* represents a conductor that is movable on the rails *A* and *B* which form part of the circuit. The current flowing through *C* causes it to move along the rails to the right or left according to the direction of the current. This is the fundamental principle of the motor.

Thus we have a means of imparting mechanical motion to a body at the expense of electrical energy.

Direction of Motion. A simple method of obtaining the direction of motion when the direction of the current and of the lines of force are known, is by means of Fleming's rule. In finding the direction of the current in generators the *right* hand is used. In finding the direction of motion of motors the *left* hand is used. The thumb, forefinger, and middle finger of the left hand are held at right angles to each other; then if the forefinger shows the direction of the lines of force, and the middle finger the direction of the current, the thumb will show the direction of motion.

By applying this rule to the case shown in Fig. 1 it appears that the motion of C will be to the right. If the current was in the opposite direction C would move to the left. If the direction of the lines of force was downward through the paper, the direction of current remaining as represented, C would move to the left. If both the direction of current and lines of force were opposite to that represented in Fig. 1, then by the rule it is evident that the motion of C will still be to the right.

Interchangeability of Motors and Dynamos. There is essentially no difference between a motor and a dynamo. In fact dynamos usually may be run as motors or motors may be run as dynamos. If a current is passed through the armature of a dynamo we have the conditions for a motor, and the armature will rapidly rotate.

In view of these facts it is evident that nearly all that has been said in regard to generators, applies equally well to motors. Therefore in this section it is only necessary to consider the special characteristics of the latter.

Motion of the Armature. Fig. 2 represents a ring armature which is supplied with a current of electricity from some external source. The direction of the lines of force of the field is from right to left. The direction of the current in a ring armature should be taken as that in the wire on the outside, because the wire on the outside of the ring cuts a greater number of lines of force than the wire on the inside of the ring. Nearly all lines pass through the armature core, as in Fig. 3.

Considering the right-hand half of the ring we see that the direction of the current in the winding on the outside is downward through the paper. By applying Fleming's rule, using the left

hand, it is seen that the rotation of the armature will be left-handed. Now considering the left-hand half of the ring (the current in the winding on the outside being upward through the paper) the rotation of the armature is found to be left-handed. Hence each half of the armature causes a left-handed rotation.

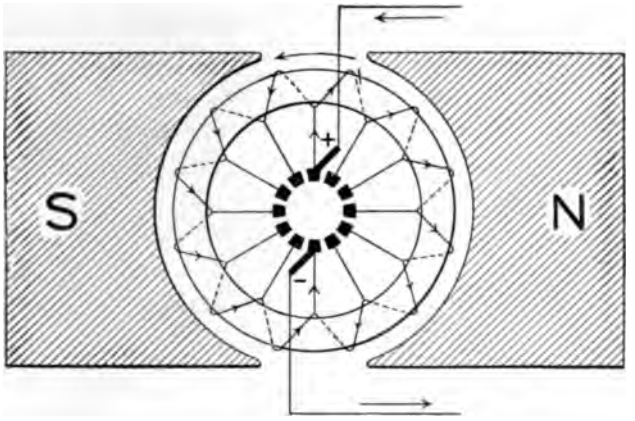


Fig. 2.

Reversal of Rotation. By reversing *either* the direction of the lines of force *or* the direction of the armature current, the direction of rotation will be reversed. If *both* the lines of force and the current are reversed the direction of rotation will be unchanged. These statements may be verified by the application of Fleming's rule to the different cases.

Therefore, the direction of rotation of a motor armature may be changed by reversing *either* the field of force *or* the armature current, but not both.

Generators Run as Motors. By applying Fleming's rule as to the direction of rotation of motors it is easy to determine in what direction the armature of a generator will rotate when run as a motor.

If a series generator is run as a motor the armature will rotate in the opposite direction to that in which it has been driven because both the armature and field currents are reversed; it is, therefore, necessary to reverse the brushes. If the original direction of rotation is desired then either the armature or field connections must be reversed.

The armature of a shunt generator will rotate in the same direction when run as a motor, because while the armature current is reversed the field current has the same direction as when run as a generator.

The armature of a compound generator will have its direction of rotation reversed when run as a motor if the series winding has a greater magnetizing effect than the shunt winding. The direction of rotation will remain the same if the magnetizing effect of the shunt coil is greater than that of the series winding. This will be understood when it is considered that in the generator the field excitation is that due to the *sum* of the magnetizing effects of the shunt and series coils, whereas when run as a motor it is their difference. Of course reversing the connections of either the series or shunt winding would then cause the field excitation to be that due to their sum, the direction of rotation depending upon which connections were changed. If the connections of the series coil were changed the direction of rotation would remain as before; changing the connections of the shunt coil would reverse the rotation.

Counter Electromotive Force. We have learned that when a conductor moves across lines of magnetic force, an E. M. F. is generated in the wire, and that this is the fundamental principle of the dynamo. Now, when the armature of a motor is caused to rotate, by passing a current through it, the very act of moving across the field of the motor causes the generation of an E. M. F. This E. M. F. is opposed to that applied to the motor and is known as the *counter* E. M. F.

The greater the speed of the armature, the greater will be this counter E. M. F., as a larger number of lines of force are cut in a given time. Also the greater the counter E. M. F. the less will be the drop of potential in the armature, for the effective E. M. F. is reduced as the counter E. M. F. increases. The strength of the armature current will therefore depend upon the speed. When the armature is forcibly restrained from rotating, the current is at its maximum, being equal to the E. M. F. applied at the brushes divided by the resistance. On releasing the armature, the strength of the current gradually decreases as the motor comes up to speed.

Motor Equation. The drop of potential in a motor armature is equal to the applied E. M. F. minus the counter E. M. F. Hence from Ohm's law, we have,

$$I = \frac{E - e}{r}$$

where I is the armature current, E the E. M. F. applied at the brushes, e the counter E. M. F., and r the armature resistance. This is the fundamental *motor equation.*

From this equation it is evident that when e is small, that is, before the motor is up to speed, the armature current will be large. As the speed increases the counter E. M. F. is increased causing the current to become less and less until at full speed the current is normal.

Example. — The armature resistance of a motor is .54 ohm, the E. M. F. at the brushes is 215 volts, and the counter E. M. F. is 190 volts. What current passes through the armature?

Solution. — By the motor equation,

$$I = \frac{215 - 190}{.54} = 46.3 \text{ amperes (nearly).}$$

Ans. 46.3 amperes.

Example. — If the armature current is 14.1 amperes, the voltage at the brushes 109 and the armature resistance 1.69 ohms, what is the counter E. M. F.?

Solution. — Substituting in the motor equation,

$$14.1 = \frac{109 - e}{1.69}$$

$$e = 85.2 \text{ volts (approx.).}$$

Ans. 85.2 volts.

The Distortion of Field which occurs in a dynamo is also present in a motor, being due to the fact that the lines of force of the armature field are nearly at right angles to those of the field magnets, the amount of distortion being dependent upon the relative strength of the two fields.

In a motor the direction of the armature current and consequently the direction of its field is opposite to that in a dynamo. This causes the resultant field of a motor to be as represented in Fig. 3. It is evident that the neutral points are shifted *backwards*, whereas in the generator they are shifted forwards. This figure

should be compared with the corresponding one for a dynamo, Fig. 35, in the section devoted to *Theory of Dynamo-electric Machinery*. Hence, to place the brushes at the neutral point of a motor they are shifted in an opposite direction to that of rotation. The greater the armature current the greater will be the distortion of field, and the more the brushes must be shifted backwards.

If the field magnets are made very powerful as compared with the armature, the distortion of field will be very slight or will be practically absent. In that case the brushes need not be shifted for variations in the load.

As seen in Fig. 3 the density of the lines of force is greater at the horns A, which the armature is approaching, than at the horns *B*, from which it is receding; consequently the induced Foucault currents and the heating will be greater in the horns *A*,

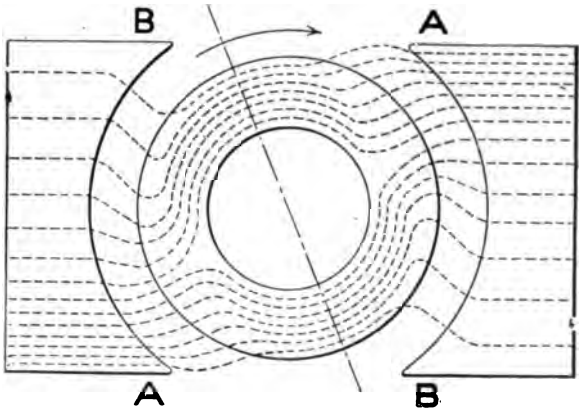


Fig. 3.

while in the generator the heating is greater in the horns from which the armature is receding. In the case of the motor the air current tends to equalize the difference of temperature between the horns *A* and *B*, because cool air is drawn in at *A* and ejected somewhat warmer, at *B*; whereas in the generator cool air is drawn in at the cooler horns which tends to increase the difference of temperature.

Efficiency. The *commercial efficiency* of a motor is equal to the actual output divided by the actual input, or

$$commercial\ efficiency = \frac{output}{input}.$$

Or $$\textit{commercial efficiency} = \frac{\textit{input} - \textit{losses}}{\textit{input.}}.$$

The losses in a motor may be given under two heads:

The **electrical** losses,

(a) Armature wire I^2 R loss.

(b) Field wire I^2 R loss.

The **stray power** losses,

(c) Friction of bearings.

(d) Friction of brushes.

(e) Friction due to air resistance.

(f) Waste currents in coils during commutation.

(g) Foucault currents in armature core.

(h) Hysteresis in armature core.

(i) Foucault currents in armature wire.

(j) Foucault currents in pole pieces.

The electrical losses in the field and armature windings are due to the heating of the conductors by the current flowing through them. This loss as we have learned varies directly as the square of the current and as the resistance, that is, as $I^2 R$.

The stray power losses are small when considered separately, excepting friction of bearings, but collectively they usually amount to as much as the electrical losses. The stray power losses are practically constant for any load.

The *electrical efficiency* is the efficiency of the motor when only the electrical losses a and b are considered. This may be expressed as the input minus the electrical losses, divided by the input, or

$$\textit{electrical efficiency} = \frac{\textit{input} - \textit{electrical losses}}{\textit{input}}.$$

The electrical efficiency, therefore, only indicates the amount of the electrical losses and does not take into account the stray power losses.

The *efficiency of conversion* or *gross efficiency* of a motor is the ratio of the output to the useful electrical energy or to the input minus the electrical losses, that is,

$$\textit{gross efficiency} = \frac{\textit{output}}{\textit{input} - \textit{electrical losses}}.$$

The gross efficiency, therefore, takes into account only the stray power losses.

When no efficiency is specified, the commercial efficiency is understood.

The commercial efficiency of small motors ranges from 50 % to 75%. Motors of from three to ten horse-power have efficiencies which range from 75% to 85 %. Larger motors should have an efficiency in the neighborhood of 90%.

Example.—A motor has at its terminals an E. M. F. of 220 volts, and takes a current of 26 amperes. The output is 5.94 horse-power: what is the efficiency of the motor?

Solution.—Input $= 220 \times 26 = 5720$ watts.

$$= \frac{5720}{746} = 7.67 \text{ H. P. (approx.)}$$

$$\text{Efficiency} = \frac{5.94}{7.67} = .774 + \text{ or } 77.4 + \%$$

Ans. 77.4 + %

Siemens' Law of Efficiency. This law is as follows: The efficiency of a motor is equal to the ratio of the counter E. M. F. to the applied E. M. F.

This law assumes that the only loss existing is that in the armature wires, or $I^2 r$, where I is the armature current and r the armature resistance. Hence it is assumed that there are no stray power losses, and also that we have a magneto motor.

The proof of the law is as follows:

$$\text{Efficiency} = \frac{input - losses}{input}.$$

$$\text{Input} = E I.$$

$$\text{Losses} = I^2 r.$$

Hence,

$$\text{Efficiency} = \frac{E I - I^2 r}{E I}$$

$$= \frac{E - I r}{E}$$

By the motor equation

$$I = \frac{E - e}{r}, \text{ then } Ir = E - e.$$

Therefore,

$$\text{Efficiency} = \frac{E - (E - e)}{E}$$

$$\text{or, Efficiency} = \frac{e}{E}.$$

That is, the efficiency is equal to the counter E. M. F. divided by the applied E. M. F.

Hence the greater the counter E. M. F. the higher the efficiency of the motor. If the counter E. M. F. could become equal to the applied E. M. F., the efficiency would be equal to unity, or 100 per cent, but in that case no current would pass in the armature and consequently there could be no output.

Jacobi's Law of Maximum Output. This law may be stated as follows: The maximum amount of work is done by a motor when the speed is such that the counter E. M. F. is one-half of that applied to the motor.

The proof of this law is most easily understood by the aid of a diagram. Fig. 4 represents a square having the length of the side equal to E, the applied E. M. F. The distance $A\ B$ is equal to e, the counter E. M. F. The diagonal is drawn from A, and the horizontal from B. At the point where this crosses the diagonal, a vertical is drawn. The distance $B\ C$ is evidently equal to $E - e$.

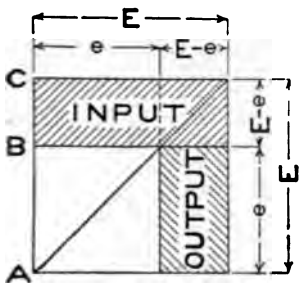


Fig. 4.

The input is equal to $E\ I$, and as $I = \frac{E - e}{r}$, then

$$\text{input} = E\ I = \frac{E\ (E - e)}{r}.$$

The output is equal to the input minus the losses, that is,

$$\text{output} = \frac{E\ (E - e)}{r} - I^2\ r$$

$$= \frac{E\ (E - e)}{r} - \left(\frac{E - e}{r}\right)^2 r$$

$$= \frac{E\ (E - e) - (E - e)^2}{r}$$

$$= \frac{e\ (E - e)}{r}.$$

In these values of output and input a constant, r, appears in the denominator of each, therefore the relation of the output and input will be as the magnitude of the numerators. That is, we may represent output by $e\ (E - e)$, and input by $E\ (E - e)$. Referring to the figure, it is evident that the area of the rectangle *output* is equal to $e\ (E - e)$; that of the rectangle *input* is equal to $E\ (E - e)$.

Now if in Fig. 4 the counter E. M. F. is decreased the output will increase until it becomes a square, and will evidently then have a maximum value as shown in Fig. 5. The counter E. M. F. is then one-half the applied E. M. F. Hence the maximum amount of work is done by a motor when the counter E. M. F. is one-half of that applied.

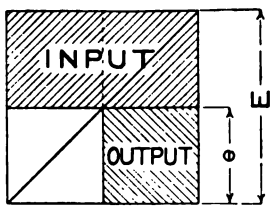


Fig. 5.

When a motor is doing a maximum amount of work the value of the current, as found by the motor equation, is one-half of that which would pass when the motor is at rest, that is, when no counter E. M. F. is generated.

It is evident from Fig. 5 that when the output is a maximum it is equal to one-half the input, consequently the efficiency is then 50%. This is also seen to be true from Siemens' law because e is one-half E, hence the efficiency is equal to 50%.

On account of the assumptions which must be made in the proof of these laws they are not strictly followed in practical machines.

Torque. The torque of a motor is its tendency to turn. It is usually expressed in pound-feet, and is equal to the pull in pounds exerted at one foot radius.

If it is known that a certain number of pounds pull is exerted at the circumference of a pulley whose radius is known, the torque is obtained by multiplying the pounds pull by the radius in feet. On the other hand, if the torque is known the pull at any radius is found by dividing by the radius.

The number of foot-pounds of work done by one revolution of a shaft is equal to the torque multiplied by $2\ \pi$, for $2\ \pi$ is the circumference in feet of a circle of one foot radius, and torque is the pounds pull at that distance, hence the product of the pounds

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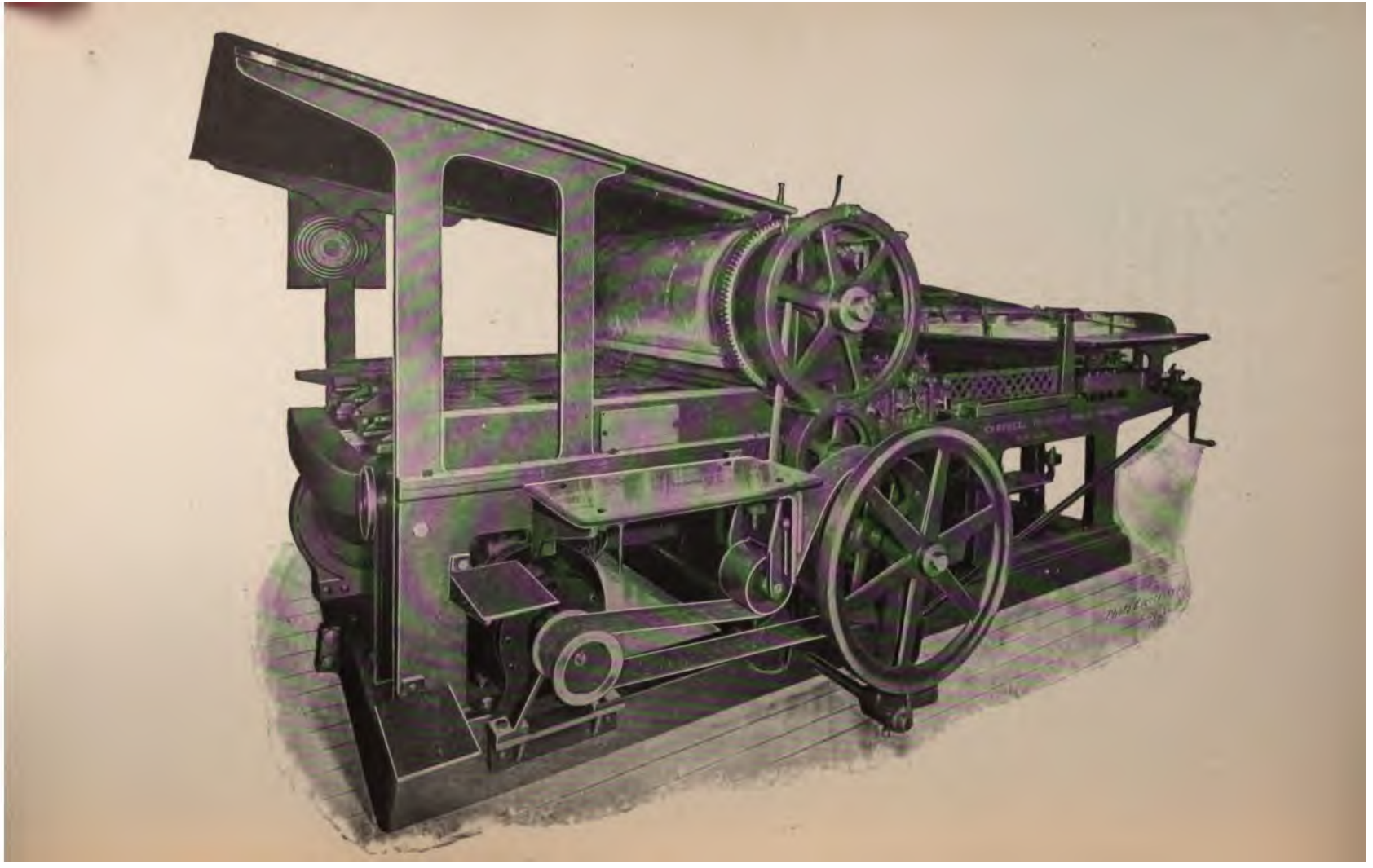


pull and distance through which it acts gives the work done. If there are n revolutions per minute, the foot-pounds of work done per minute will be $2 \pi n T$, where T is the torque; hence the horse-power will be

$$\text{H. P.} = \frac{2 \pi n T}{33{,}000}.$$

If the horse-power and number of revolutions are known, the torque may be found from the formula

$$T = \frac{\text{H. P.} \times 33{,}000}{2 \pi n}.$$

If the torque and the horse-power are known, the number of revolutions may be found from the formula

$$n = \frac{\text{H. P.} \times 33{,}000}{2 \pi T}.$$

In a given armature, the torque varies directly as the product of the field strength and armature current, or

$$T \text{ varies as } f I$$

where T is the torque, f the field strength, and I the armature current. That is, if the field is kept constant the torque will vary directly as the armature current, and if the latter is kept constant the torque will vary directly as the field strength.

Measurement of Torque. The Prony brake may be used to measure the torque of a motor. The arrangement is shown in Fig. 6. P is a pulley on the armature shaft; the blocks A and C

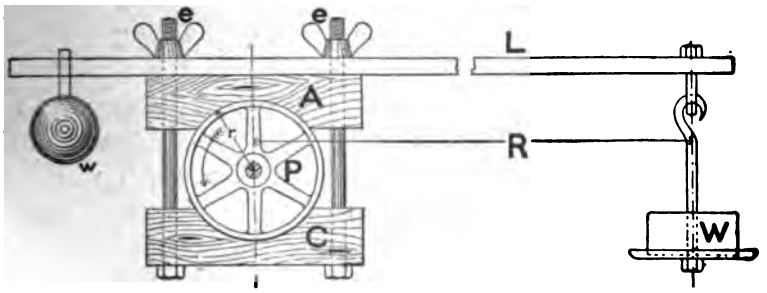


Fig. 6.

bear against the face of the pulley, the pressure being regulated by the wing-nuts e. The lever L which is clamped to A, is counterbalanced by the weight w. The weight W which is supported by

the lever has such a value as will keep the lever horizontal when the pulley is rotating.

To find the torque at a certain speed or when the motor take a certain current, the pressure on the pulley is adjusted until the speed or current is that desired. The weight W is made to balance the tendency of the lever to turn. The torque is then found by multiplying the measured distance R in feet, by the weight W in pounds.

Example.—In finding the output of a motor the distance R was 2.5 feet, the weight W was 12.4 pounds, and the number of revolutions of the motor was 1,400 per minute. What was the output of the motor in horse-power?

Solution.— Torque $= 2.5 \times 12.4 = 31$. pound-feet.

$$\text{H. P.} = \frac{2\,\pi\,n\,T}{33{,}000}$$

$$= \frac{2 \times 3.142 \times 1{,}400 \times 31}{33{,}000}$$

$= 8.25 +$ Ans. 8.25 + H. P.

Example.— What pull at the rim of a pulley 10 inches in diameter will be given by a 6 H. P. motor running 1,200 revolutions per minute?

Solution.— $$T = \frac{\text{H. P.} \times 33{,}000}{2\,\pi\,n}$$

In this case H. P. $= 6$. $n = 1{,}200$.

Therefore

$$T = \frac{6 \times 33{,}000}{2 \times 3.142 \times 1{,}200} = 26.2 + \text{ pound-feet.}$$

But T = pounds pull × radius in feet.

= pounds pull × $\frac{5}{12}$

Therefore pounds pull $= 26.2 \times \frac{12}{5} = 62.7$ lbs. (approx.)

Ans. 62.7 lbs.

Speed. To arrive at a general expression which will show upon what factors the speed of a motor depends, we shall make use of the motor equation,

$$I = \frac{E - e}{r}.$$

Let s represent the speed of rotation, a the number of conductors on the surface of the armature, f the field strength, and k

a constant. As the E. M. F. generated by an armature moving in a field depends upon the speed, number of conductors, and strength of field, the counter E. M. F. of a motor will be equal to

$$e = s\,a\,f\,k.$$

Substituting this value in the motor equation, we have

$$I = \frac{E - s\,a\,f\,k}{r} \quad \text{or} \quad I\,r = E - s\,a\,f\,k,$$

therefore $s\,a\,f\,k = E - I\,r$, and $s = \dfrac{E - I\,r}{a\,f\,k}$.

The armature resistance of a motor is usually very small, hence the product $I\,r$ would be small and may be neglected.

Therefore the expression for speed may be written

$$s = \frac{E}{a\,f\,k}.$$

From this expression it is evident that the speed varies *directly* as the E. M. F. applied at the brushes if the number of armature conductors and the field strength are constant. An increase in E causes a greater current to pass through the armature, which, acting upon the same field strength, causes an increase of speed, provided the torque exerted is kept constant.

If the number of armature conductors and the applied E. M. F. are constant, the above expression shows that the speed varies *inversely* as the field strength, that is, if the field is weakened the speed is increased or if the field is strengthened the speed is decreased. This is true for if the field is weakened the counter E. M. F. generated by the motor will be less allowing a greater current to pass in the armature. This will tend to increase the torque but if that is kept constant, the speed will increase, a higher speed being now required to generate the same E. M. F. as was the case when the field was stronger.

If the field strength and applied E. M. F. are constant, the speed varies *inversely* as the number of armature conductors, that is, a decrease in the number of armature conductors increases the speed. If a reduction is made in the number of conductors the motor must evidently run at a higher speed in order to generate the same counter E. M. F. as before, the torque being kept constant.

Windings of Motors. As in the case of a dynamo the common windings of a motor are shunt field winding, series field winding, and compound field winding.

The motor may be supplied with electrical power at a constant potential or the current may be constant.

SHUNT MOTORS ON CONSTANT POTENTIAL CIRCUITS.

Torque. As the torque of a motor with a given armature varies as the product of the armature current and field strength, if the field strength is constant the torque will vary directly as the strength of the armature current. The shunt motor on a constant potential circuit will have a constant current passing through the field coils, consequently the field strength will remain constant, and the torque will vary only as the strength of the armature current.

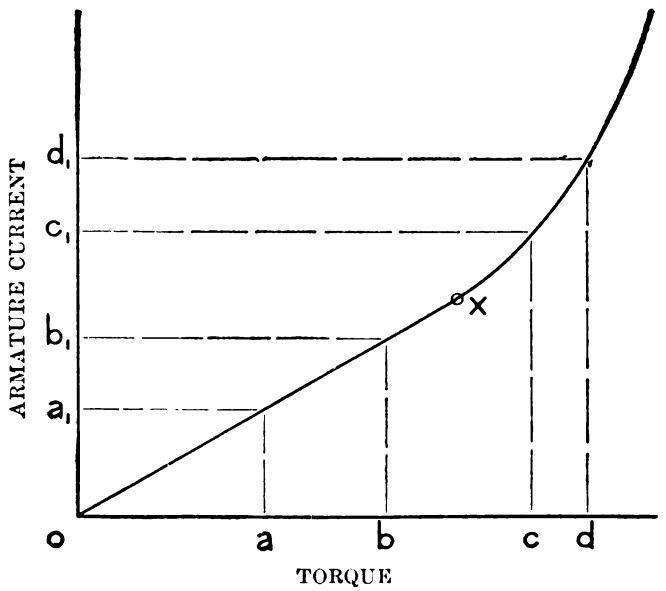


Fig. 7.

This is represented by the torque curve in Fig. 7. In this plot the abscissae *o a*, *o b*, *etc.*, represent the torque and the

ordinates $o\ a_1$, $o\ b_1$, *etc.*, the armature current, that is, when the torque has a value represented by $o\ a$ the corresponding value of the armature current will be $o\ a_1$. It is evident that from o to the point x the plot is a straight line, an increase in the armature current causing a proportional increase in the torque. Beyond point x the line is curved this being due to distortion of field by the large armature current. Here a considerable increase in the current as $c_1\ d_1$ produces but a small increase $c\ d$ in the torque. A good machine should not have much distortion of field at or under normal load.

Constant Speed. The speed of a shunt motor on a constant potential circuit is practically constant for any load.

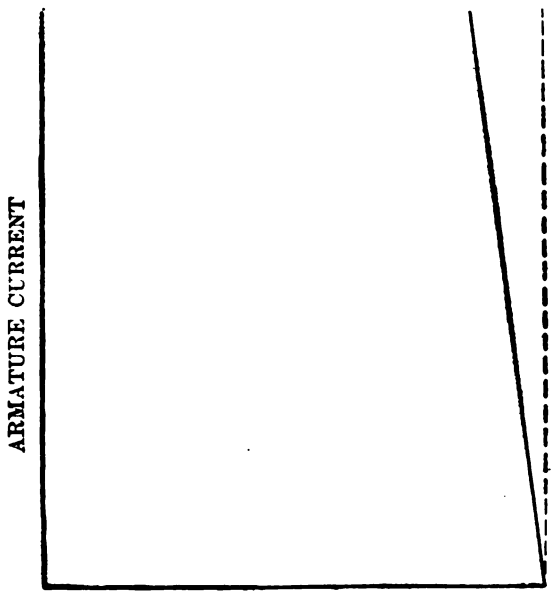


Fig. 8.

This is seen to be true from our approximate expression for speed,

$$s = \frac{E}{a f k}.$$

For since E is constant, f will be constant, and in a given armature a will be constant, therefore s will have a constant value.

As a matter of fact the speed will fall *slightly* as the torque increases. An increase of torque causes the armature current to be greater. As the applied E. M. F. is constant the increase in the armature current can only occur by decreasing the counter E. M. F., this being evident from the motor equation. Then if a decrease in the counter E. M. F. is necessary the speed must be slightly less.

This is represented in Fig. 8, which shows a gradually falling speed as the armature current is increased. In the figure, as indicated, the abscissae represent the speed, and the ordinates the armature current.

There are many methods of varying the speed of a shunt motor, all of which depend upon the variation of E. M. F. applied at the brushes, variation of field strength, or variation in the number of armature conductors. We will consider these methods in detail.

Variation of E. M. F. at the Brushes. We have seen that the speed of a motor varies directly as the E. M. F. applied at the brushes.

If a resistance is connected in series with the armature there will be a certain number of volts lost by the armature current passing through this resistance, consequently the voltage at the brushes will be less and the speed decreased. This method is illustrated in Fig. 9, the resistance *R* being inserted in the armature circuit. The commutator is represented by *C*, and the shunt field windings by F. The greater the resistance inserted the less will be the speed.

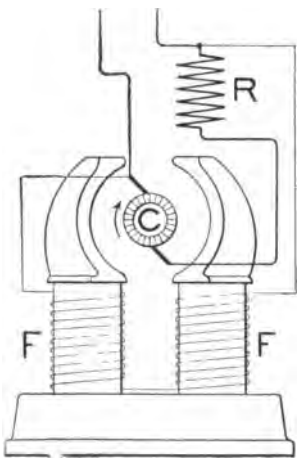
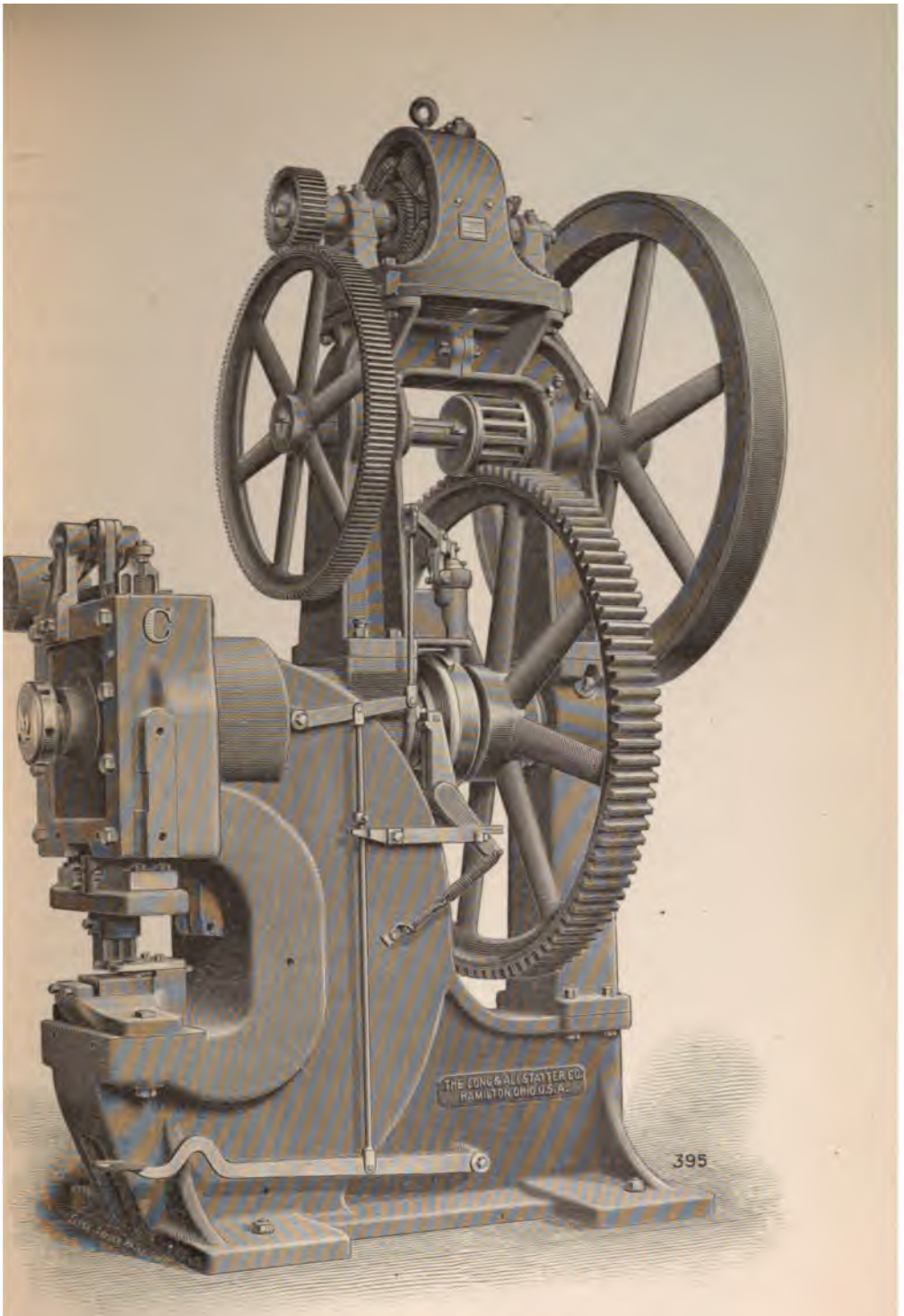


Fig. 9

Problem. — Suppose a shunt motor is to be used on a 220 volt circuit, the current taken by the armature at full load being 16 amperes and the speed 1,000 revolutions per minute. It is desired that the motor should run at $\frac{1}{2}$ speed when the torque is $\frac{3}{4}$ of that at full load. What resistance *R*, is it then necessary to insert in the armature circuit?



MACHINE FOR PUNCHING OR SHEARING.
Showing Motor and Gearing.
The Long and Allstatter Co.

PUBLIC LIB

Solution. — Here $E = 220$, the normal current $I = 16$, and the speed $s = 1{,}000$ revolutions per minute.

We have seen that the expression for the speed of a motor is

$$s = \frac{E - Ir}{a f k},$$

and, as only the voltage E is to be varied, the denominator $a f k$ is a constant. Hence the formula may be written

$$s = \frac{E - Ir}{\text{constant}}.$$

As the resistance R is in series with r, and as r is very small we can neglect it. With R inserted the formula becomes

$$s = \frac{E - IR}{\text{constant}}.$$

The value of the denominator is easily found, for, when R is cut out of the circuit, $IR = 0$, and the speed is normal being 1,000 revolutions. Substituting these values in the equation we have

$$1{,}000 = \frac{220 - 0}{\text{constant}}$$

$$\text{constant} = .220.$$

Hence

$$s = \frac{E - IR}{.220}.$$

The torque is to be $\frac{3}{4}$ of that at full load, and as the field strength is constant the torque is decreased by decreasing the armature current I. Hence at $\frac{3}{4}$ torque the current will be $\frac{3}{4}$ of that at full load or $\frac{3}{4} \times 16 = 12$ amperes. The speed is to be $\frac{1}{2} \times 1000 = 500$ revolutions per minute.

Substituting these values in the preceding equation we obtain

$$500 = \frac{220 - 12R}{.220}.$$

Therefore $R = 9.17$ ohms nearly.

Ans. 9.17 ohms.

The above method of regulating the speed of a shunt motor is the one most largely used, being simple and perfectly controlling

the speed at all loads. It has the disadvantage, however, of poor economy, because the energy lost as heat in the resistance is considerable, being equal to I^2R.

The resistance used for starting the motor (see page 24) must not be used for regulating the speed in the above way. The starting resistance is usually very compact, and has a relatively small surface exposed to the air. It does not heat much during the short time required for starting, but if allowed to carry the armature current continuously it is liable to burn out. Regulating resistances are often made of zigzag strips of iron, insulated with asbestos, and exposed as much as possible to the air.

Variations of Field Strength. It has been shown that an increase in the speed of a motor is obtained by weakening the field strength, and that a decreased speed is obtained by increasing the field strength.

A simple and much used method of varying the field strength is the insertion or cutting out of resistance in the field circuit. This will change the current passing in the field coils and consequently the magnetization of the field magnets.

Another method of changing the magnetizing force is by having part of the field windings of German silver, and by cutting them in or out, the field strength is varied. As German silver has a high resistance the addition of these coils increases the resistance in greater proportion than the number of turns, so decreasing the ampere-turns. This method allows a moderate variation in speed, is easily operated, and is not expensive.

The objections to any method of regulating the speed by varying the field strength are:

1. If the speed is decreased the torque remaining constant, the motor gives out less power but requires at the same time an increased expenditure of energy in the fields.

2. It is customary in order to get the full power of a motor, to have the field magnets at or near the point of saturation at normal speed. But if it is desired to run the motor at a slower speed, the fields must be below their point of saturation at normal speed, since to decrease the speed the field strength must be increased. Hence at normal speed the fields are not worked to their full capacity, and the full power of the motor is not utilized. That

is, the motor is larger than it otherwise would be, which means additional expense.

3. When the fields are weakened to increase the speed, the armature current causes greater distortion of the field and sparking is greatly increased.

If the resistance of the magnetic circuit is varied, the field strength will also be changed, and an increase of the magnetic resistance will cause an increase in the speed. This method of controlling the speed is not only usually difficult to apply but is also uneconomical. The magnetic resistance can be varied in three different ways: (*a*) the lines of force passing through the armature can be diverted through a movable piece of iron placed near the pole pieces, (*b*) the length of the air gap can be varied by having the relative position of field magnets altered, and (*c*) the cross section of the air gap can be varied by changing the relative position of the armature and pole pieces.

Variation of Number of Armature Wires. We have seen that the speed may be expressed approximately

$$s = \frac{E}{a f k}.$$

If the armature is arranged so that every two wires can be connected in multiple the number of conductors will then be equivalent to $\frac{a}{2}$ having $\frac{1}{2}$ the resistance. This change will cause the new speed s' to be double the speed s. For

$$s' = \frac{E}{\frac{a}{2} f k} = \frac{2 E}{a f k},$$

which is twice the value of s.

If every two wires are again connected in multiple the number of conductors is $\frac{a}{4}$, the speed then being $4\ s$.

The same result is obtained in practice by changing two or more independent windings from series to multiple. These windings may be on the same armature core, or on separate cores on the same shaft, each winding requiring a separate pair of brushes.

The same result may be obtained by coupling separate motors to the same work.

Fig. 10 represents the changes where there are four independent armature windings or four independent motors. The separate commutators are represented by *c*, and field windings by *f*, the connections of the latter being the same for all speeds. In case *A* the brushes, and hence the armature windings are connected in series.

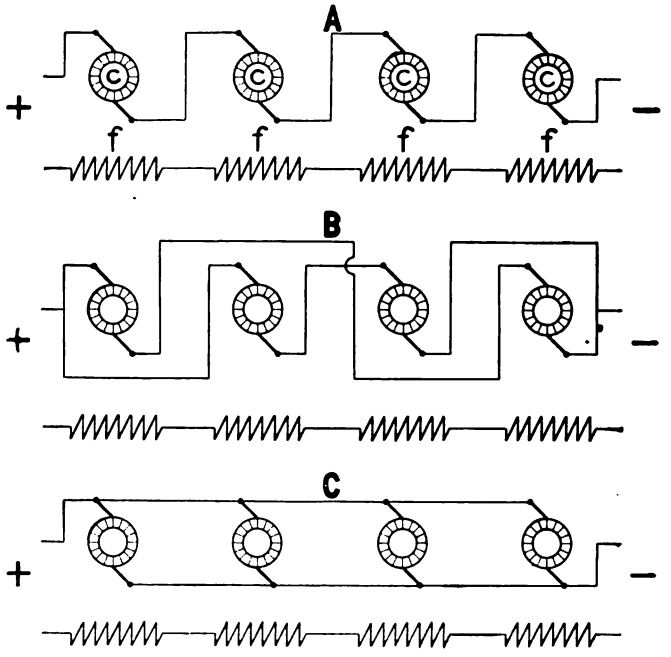


Fig. 10.

The number of armature windings being large the speed is small. In case *B* the armatures are connected in series multiple. The number of windings being then equivalent to $\frac{1}{2}$ of the number in the first case, the speed will be twice as great. In case *C*, the windings are all connected in multiple, hence the speed will be four times that in case *A*, and twice that in case *B*. We have, therefore, in case *C* full speed, in case *B* $\frac{1}{2}$ speed, and in case *A* $\frac{1}{4}$ speed.

This method of regulating the speed is satisfactory in regard to efficiency, for, if a constant torque is exerted by the motors

throughout the above changes, the current taken by each motor will have a constant value. Hence in case B the current used will be twice that in case A; but in the former case the speed is twice as great, and although the energy consumed is twice as much, the output is also double. Therefore the efficiency remains unchanged. Similarly the efficiency remains unchanged in case C.

The objection to this method is, of course, the use of several motors, which involves extra expense.

Variation of Position of the Brushes. By shifting the brushes from the neutral point the speed of the motor can be increased. This will be understood from Fig. 11.

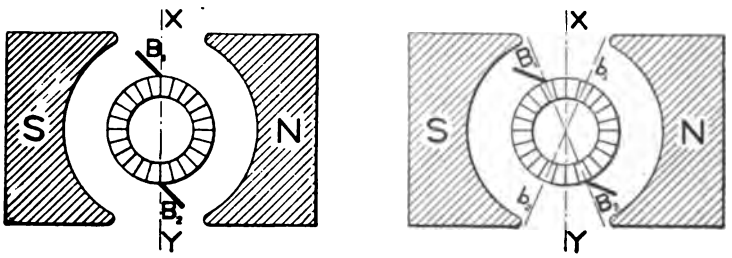


Fig. 11.

The neutral line is represented by X Y, and in the left-hand figure the brushes B_1 B_2 are at the neutral point, the entire counter E. M. F. generated, that is, by the conductors from B_1 to B_2, being effective. In the right-hand figure the brushes are shown shifted and in this position the effective counter E. M. F. is reduced. In this case the counter E. M. F. generated by the conductors from B_1 to X opposes that generated from X to B_2, the effective counter E. M. F. being reduced to that generated by the conductors from b_1 to B_2, and likewise from b_2 to B_1. For constant torque, however, the armature current must be constant when the field strength is not changed, therefore the counter E. M. F. must not be reduced. As a smaller number of conductors are now available to generate the counter E. M. F., the speed of the motor must be increased. That is, by shifting the brushes from the neutral point the speed is made higher.

This method is really equivalent to reducing the number of armature conductors. It has the great objection of causing exces-

sivesparking and of being injurious to the commutator, brushes, and armature winding.

Starting Resistance. If a motor armature is restrained from rotating the current passing through it will be very large, being equal to $\frac{E}{r}$, since no counter E. M. F. is generated. This excessive current would damage the armature, hence it is necessary to have a large resistance in the armature circuit to make the current small while the motor is coming up to speed. That is, before starting a motor, a large resistance should be connected in the armature circuit which is gradually reduced as the motor comes up to speed.

In order not to have the armature current in starting larger than the normal current, the resistance inserted, R, should be $R=\frac{E}{I}$, where E is the applied E. M. F. and I the normal armature current. For motors of more than 15 horse-power, however, R should be greater than $\frac{E}{I}$ in order not to throw a heavy load suddenlyon the driving dynamo.

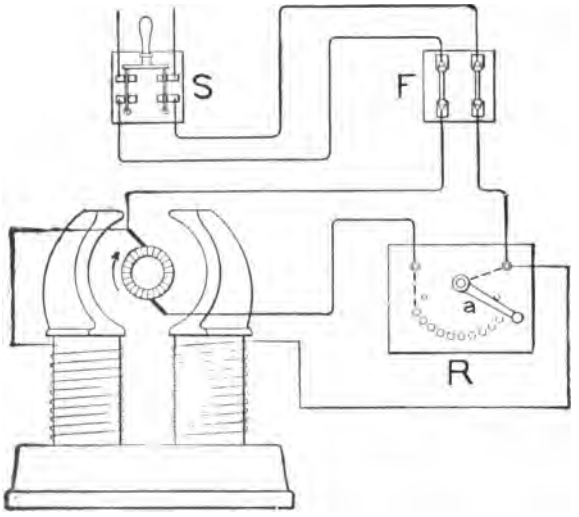


Fig. 12.

Connections. The connections for a shunt motor on constant potential mains are shown in Fig. 12. From the mains the con-

ductors lead to the double pole switch *S*. The fuses *F*, made of an easily fusible metal, are placed on both lines to protect the motor from dangerous currents caused by short circuits. The fuses are of such a cross section that they melt when a current greater than the safe one for the motor passes through them, and so break the circuit. The starting resistance is *R*, and is arranged so that turning the arm *a* will close the armature circuit inserting the full resistance *R*, and then gradually reduce it until it is all cut out. The switch *S* is placed outside the other connections so that when it is opened they are entirely disconnected and may be handled without fear of receiving a shock.

Starting. After making sure that the arm of the starting resistance is in the position so that the armature circuit is disconnected, the switch *S* is closed, and the fields then become fully charged before any current flows through the armature. The armature circuit is then closed through the resistance *R*, and as the motor speeds up this resistance is gradually cut out. As the speed of the motor increases, the counter E. M. F. becomes greater and the armature current less, allowing the resistance *R* to be cut out.

Stopping. In stopping the motor the switch *S* is first thrown. After the motor has come to rest the arm *a* of the resistance is then turned to the position ready for starting.

While coming to rest the motor runs as a generator and the field current is supplied by the armature. The direction of this current being the same as before, its strength will *gradually* decrease as the motor slows down, thus allowing a *gradual* decrease in the field strength.

If the armature circuit is broken first, then on throwing the switch *S* the field current is cut off abruptly, and the high E. M. F. caused by self-induction produces a destructive flash at the switch; moreover a very high potential is produced in the field winding and this is likely to pierce the insulation. Also for this reason the switch should not be closed unless the motor is afterwards started.

Reversing Motors. Motors are reversed in the direction of their rotation by simply changing the relative direction of the magnetic field and the armature current. This, as we have seen

is accomplished by changing *either* the direction of the armature current *or* the field current. The former is the more common method. A motor which is to be often reversed should have powerful field magnets so that there will be practically no distortion of the field, and no lead will be necessary for the brushes. Otherwise the lead would have to be changed when the rotation is reversed.

Reversing While Running. If the direction of the armature current is reversed while the motor is running, then until the armature comes to a stop and its rotation reversed, the counter E. M. F. acts *with* the applied E. M. F. This would cause the armature current to be extremely large being equal to

$$I = \frac{E + e}{r}.$$

It is therefore necessary that a large resistance R should be inserted in the armature circuit before the current is reversed. Then before the armature stops rotating the current will be

$$I = \frac{E + e}{R + r}.$$

However, as the direction of the armature current is now changed and comparatively large, the armature is quickly brought to rest, the current gradually decreasing as e becomes less and less.

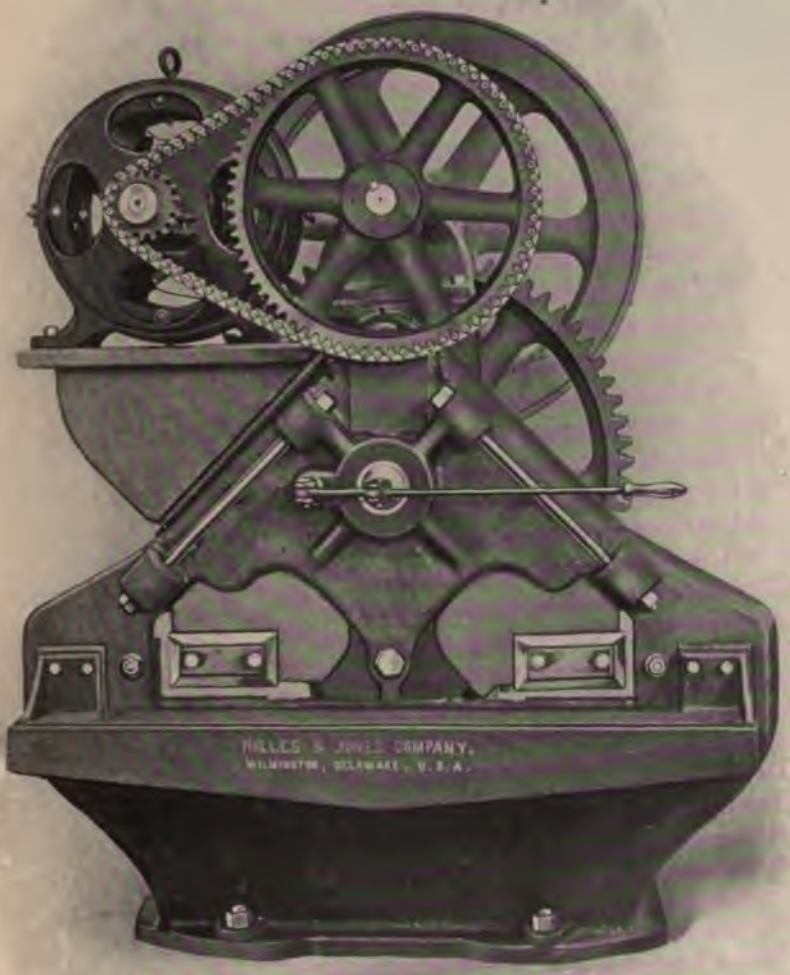
When e becomes zero, that is, when the motor has stopped,

$$I = \frac{E}{R + r}.$$

The motor now speeds up in the opposite direction, e gradually increasing but now opposing E. As the motor speeds up, R is cut out, and the current becomes normal being equal to

$$I = \frac{E - e}{r}.$$

Reversing the direction of the current in the field circuit does not produce so abrupt a change in the motion of the armature, nor does its current become so excessively large. This is so because the field magnetism does not rise rapidly on account of self-induction [illegible] in the circuit, the armature then has time to slow down considerably so that the additive e is small,



MOTOR-DRIVEN SHEAR.

Morse Chain Company.

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The reversing of the field circuit however, causes severe sparking at the switch contacts as well as being likely to injure the field wire insulation.

A motor should never be reversed while running unless in the most necessary cases, and then not without inserting in the armature circuit the full resistance.

Reversing Connections. In Fig. 13 is shown a common form of reversing switch. The two metal bars H are pivoted one at a, and one at b. A strip K of insulating material joins the two

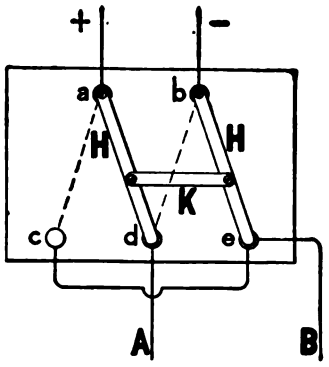


Fig. 13.

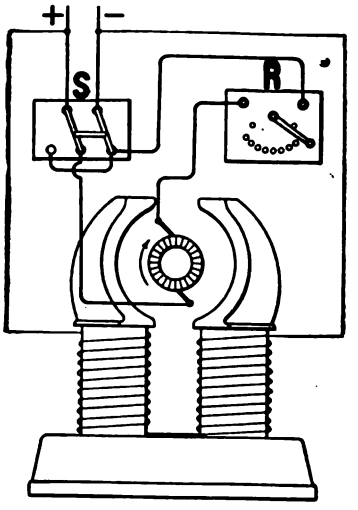


Fig. 14.

bars. In the position shown the wire A is positive and B is negative. When the bars are switched to contacts c and d in the position indicated by the dotted lines, wire B then becomes positive and A negative.

Fig. 14 shows the connections when a reversing switch S is inserted in the armature circuit of a shunt dynamo, the starting resistance being R. The reversing switch is sometimes combined with the starting resistance.

Maximum Output of Shunt Motor. We have seen that the maximum output of a motor when the only loss considered is that in the armature wires, is obtained when the armature current is $I = \frac{1}{2}\frac{E}{r}$; that is, when the strength of the current is one-half

of that which would flow if the armature was restrained from rotating, the counter E. M. F. being equal to $\frac{1}{2} E$.

Since the stray power and field wire loss for a shunt motor on a constant potential circuit are approximately constant for any load, the loss in the armature winding is the only variable loss. For this reason Jacobi's law is also true for the commercial shunt motor.

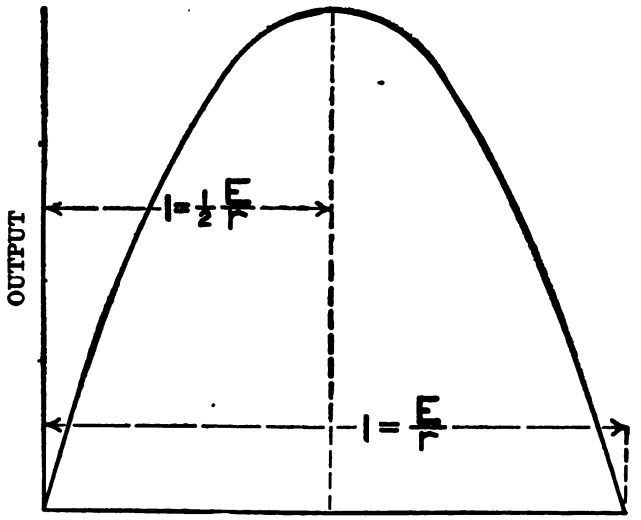


Fig. 15.

Fig. 15 shows the variation of the output with the armature current. At the beginning of the curve the current is zero, hence there could be no output. When the output has risen to its highest value, then $I = \frac{1}{2}\frac{E}{r}$ and $e = \frac{1}{2} E$. With a further increase in the current the output decreases until when $I = \frac{E}{r}$ the counter E. M. F. must be zero, that is; the motor is at rest and the output is zero.

Efficiency. Siemens' law of efficiency, $\left\{ \text{efficiency} = \frac{e}{E} \right\}$ is not closely followed by the commercial motor, since when the stray power and field wire loss is also taken into account, the efficiency will evidently be less than $\frac{e}{E}$.

It can be shown mathematically that the commercial efficiency of a shunt motor will be a maximum when the armature current has such a value that its square is equal to

$$\frac{\text{field wire loss} + \text{stray power loss,}}{\text{armature resistance}}$$

or $$I^2 = \frac{i_1^2 r_1 + S.P.}{r}$$

where i_1 is the field current and r_1 the resistance of the field winding.

The variation of the commercial efficiency of a shunt motor

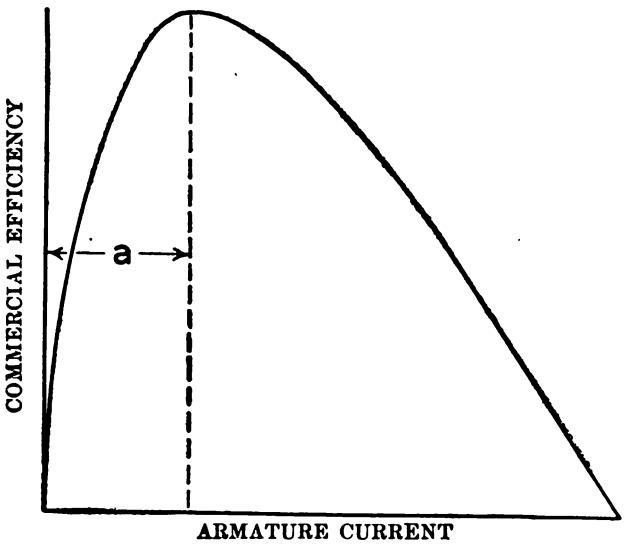


Fig. 16.

with a change in the armature current is shown in Fig. 16. It is seen that the efficiency rapidly rises with an increase in the current to its maximum value, and decreases more slowly as the current is further increased. When the efficiency is a maximum, the value of the current indicated by a in the figure is equal to

$$\sqrt{\frac{\text{field loss} + \text{stray power}}{\text{armature resistance}}}.$$

Advantage and Disadvantages of Shunt Motors. The great advantage of shunt motors is that their speed is practically constant.

The disadvantages are as follows:

1. The torque increases only in proportion to the armature current since the field strength is constant.

2. There is a high potential between the terminals of the field winding.

3. Opening the field circuit suddenly, causes a large spark and a high potential due to self-induction.

4. The many turns of fine wire of the field coils involve extra expense since fine wire costs more per pound than coarse, the labor of winding is considerable, and a large amount of insulation is necessary.

5. Where shunt motors are run intermittently it is customary to keep the field coils constantly charged, the motor being started and stopped by closing and opening the armature circuit through the resistance. Keeping the fields charged when the motor is not in use is of course a loss of energy.

Uses of Shunt Motors. A constant speed is of the greatest importance in some classes of work, and this advantage makes the use of shunt motors very extended.

Shunt motors are used in machine shops, factories, and to run printing presses, pumps, elevators, etc., or in general where good speed regulation is required.

SERIES MOTORS ON CONSTANT POTENTIAL CIRCUITS.

Torque. In the series motor the same current passes successively through the armature and field windings. We have seen that the torque depends upon the armature current and the field strength, or

$$T \text{ varies as } I f.$$

An increase in the current strength of a series motor greatly increases the torque because (*a*) the armature current is increased, and (*b*) the field strength is also increased by the larger field current. Hence in series motors the torque increases as the square of the current. Therefore on light loads the current is small and the

torque is small, and on heavy loads the current being large, the torque exerted is large. The torque increases as the square of the current, however, only when the fields are below their point of saturation. When near this point an increase in the current produces but a slight increase in the field strength, and the torque will then vary as the current strength only.

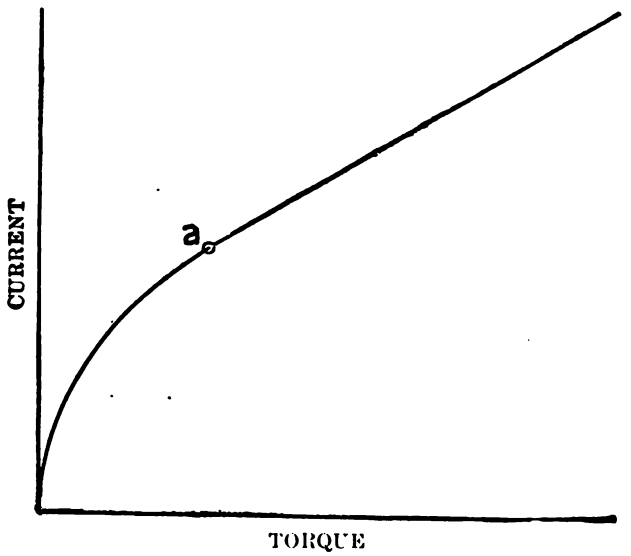


Fig. 17.

The curve in Fig. 17 shows the relation between the current taken by a series motor and the torque. Up to the point *a* the line has a considerable curve because the fields being below saturation, the torque increases as the square of the current. Beyond point *a* the fields are saturated and the torque then varies as the current only, the curve becoming a straight line.

Speed. In the case of shunt motors it was seen that the speed is nearly constant for all loads. In series motors the speed varies with the load. If part of the load is taken off of a series motor, the current becomes less, the fields are weakened, and this causes a large increase in the speed. If the load is entirely removed the speed becomes dangerously high.

Fig. 18 shows the speed curve for a series motor. It is evident from this curve that with a small current, or light torque on the motor, the speed is very large; with a large current the speed is small.

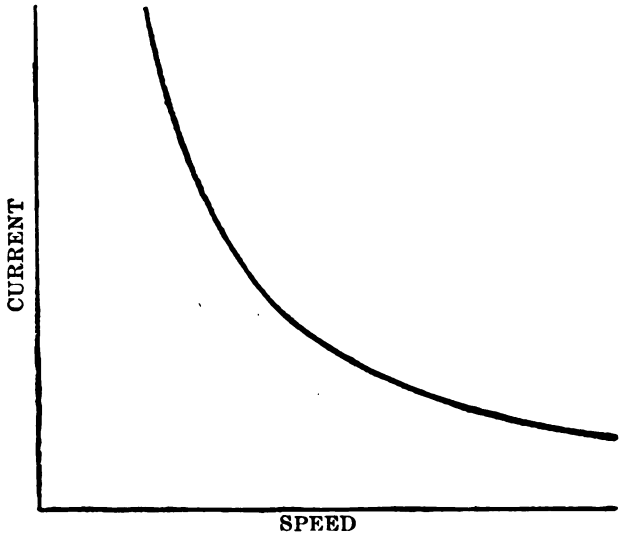


Fig. 18.

Speed Control of Series Motors. Series motors on constant potential circuits may have their speed controlled in a similar manner to that of shunt motors, there being some differences however, on account of the different field winding.

Variation of E. M. F. at the Brushes. This is the most common and most satisfactory method of controlling the speed. Fig. 19 illustrates this method, the resistance *R* being inserted to reduce the voltage available at the brushes, and consequently the speed. The current passes successively through the adjustable resistance *R*, the armature, and the field winding.

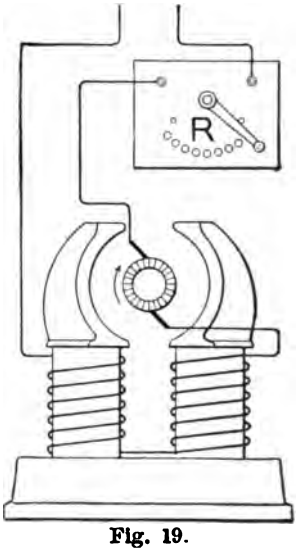


Fig. 19.

Variation of Field Strength. The field strength can be varied in several ways. If the field winding

is changed from a series coil to several coils in multiple the number of ampere-turns, and hence the magnetization will be reduced, causing the speed to be increased. Also cutting out turns or shunting a part of the field current through a by-path having an adjustable resistance will cause the speed to be increased. The latter method cannot be used for shunt motors, since the field winding is itself a shunt across the main circuit; but for series motors this method is a very useful one.

The resistance of the magnetic circuit may be varied as in shunt motors but this method is little used.

Other Methods. As in the case of shunt motors the speed of series motors may be varied by a change in the number of armature wires, as by coupling in series or multiple, and also by varying the position of the brushes. To obtain a very large range of speed there may be combinations of two or more methods.

Constant Speed. Nearly constant speed with varying load can be obtained with series motors by overwinding the field coils, that is, they may be wound so that the fields have their full strength when only one-half or even one-third of the normal current is passing. Hence with perhaps one-third load or more the fields will have a constant strength and the speed will be constant as in the case of the shunt motor. At full load the field current will be far greater than is necessary to saturate the magnets and consequently the efficiency is considerably lessened.

Starting. On starting, a rush of current tends to occur with this type of motor similar to that in case of the shunt motor; it is somewhat less however, because the field coils are in series with the armature and their resistance and self-induction reduce the excessive flow. A starting resistance is used as in the shunt motor, but can be considerably less.

Connections. These are very simple for a series motor and are indicated except the main switch and fuses, in Fig. 19; the same current passing successively through the starting resistance, armature and field winding.

Motors having more than two poles sometimes seem to have very complicated connections. Fig. 20 represents the connections for a four-pole series motor, and Fig. 21 for a four-pole shunt mo-

tor. By tracing out the connections the figures will be readily understood.

Reversing Series Motors. What has been said in regard to reversing shunt motors applies in general to series motors on constant potential circuits. Reversing while running is not so harmful to the latter as they are brought to rest sooner, since the excessive current passing through the field coils increases the field strength.

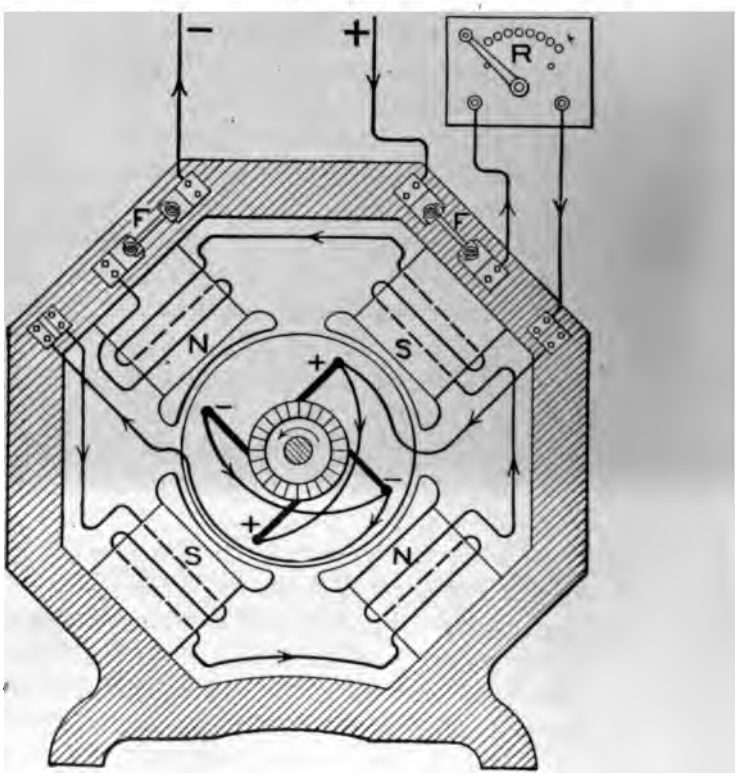
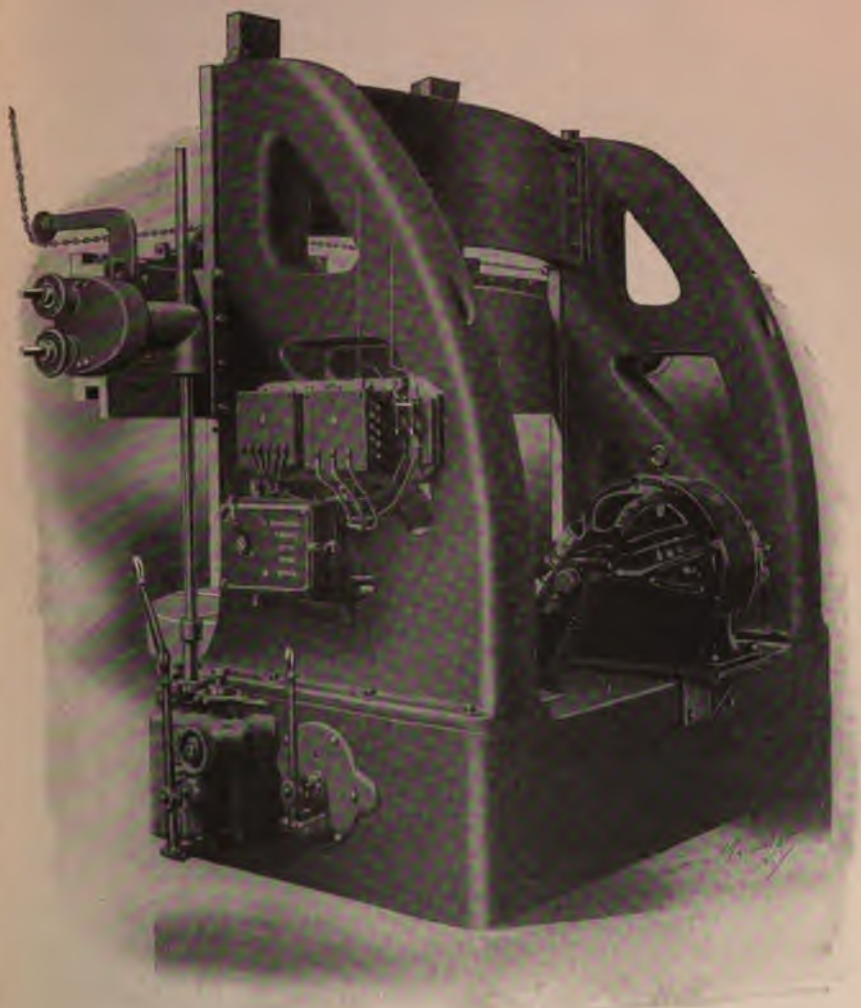


Fig. 20.

Advantages and Disadvantages of Series Motors. The advantages are:

1. The torque on overload is large; series motors are therefore well adapted for starting loads with great friction of repose.

2. The cost of the field coils is considerably less than in th



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case of shunt motors as the number of turns required is very much less.

3. The field coils and armature being in series one switch serves to cut out both at once.

The disadvantages are:

1. The speed varies with the load.

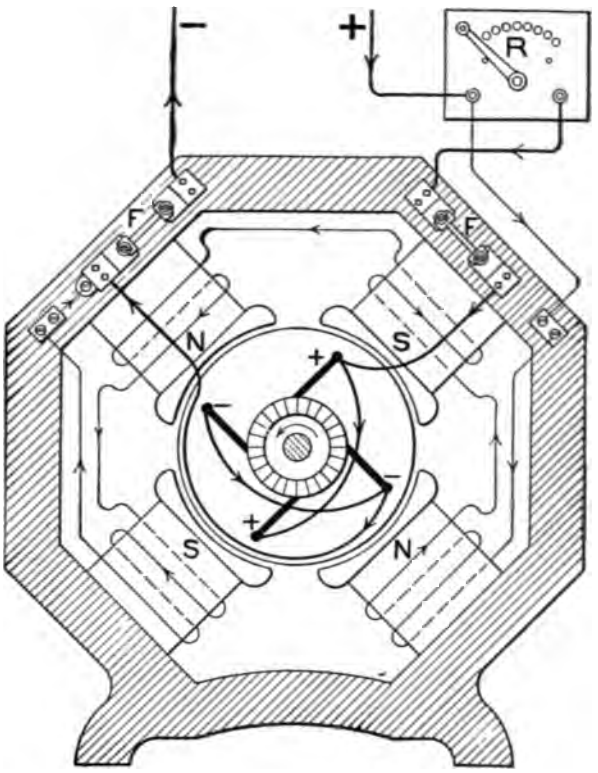

Fig. 21.

2. If the load is removed the speed becomes dangerously high and the motor may tear itself apart.

Uses of Series Motors. The most common use of this motor is in the electric railway where it is usually run on a 500 volt circuit. It is also used in operating hoists, mining machinery, and in general where the load cannot be entirely removed, where the starting torque required is large, and where a constant speed is not necessary.

COMPOUND MOTORS ON CONSTANT POTENTIAL CIRCUITS.

Compound Motors. The compound motor has two independent field windings; a shunt winding gives the main magnetization, and a series winding serves to regulate or to allow starting under heavy load.

Cumulative Compound Motor. This motor has the direction of the current in the series winding the same as that in the shunt winding and hence increases the field strength.

Such a motor has the advantage of a large torque on starting as in the case of a series motor, and an approximately constant speed as with the shunt motor. On starting the series coil is in the circuit, but is cut out when the motor has attained its full speed.

Use of Cumulative Compound Motor. The special use of this motor is where it is frequently stopped and started under a heavy load, and a nearly constant speed is desired.

Differential Compound Motor. The series winding in this motor has its current passing in an opposite direction to that in the shunt coil and consequently reduces the magnetization.

This motor gives a more constant speed than the simple shunt motor. We have seen that the speed of the shunt motor decreases *slightly* as the load increases; therefore if the field strength can be weakened with an increased load the speed can be kept up. The current in the series winding is greater the greater the load, hence the magnetization is reduced, and almost perfect speed regulation can be obtained.

It is necessary that the series coil should be inserted *after* starting the motor; otherwise its excessive current would weaken the fields so much that the starting torque would have hardly any value.

The differential motor has the serious disadvantage that with a large overload owing to the excessive current in the series coil, the field magnets may become demagnetized, and instead of the motor keeping up its speed it slows down or stops and is liable to burn out.

Use of Differential Compound Motor. Where a very constant speed is required this motor is used. The shunt motor, however, has a speed which is uniform enough for most purposes, and the differential motor is not much used now.

MOTORS ON CONSTANT CURRENT CIRCUITS.

Motors are now in use on constant current circuits to only a small extent. They cannot be made self-regulating, and therefore all have some form of mechanical governor to regulate the speed or torque. Another objection is the usually high potential of the circuits, this being a source of considerable danger.

Owing to the very general introduction of constant potential circuits, and the advantage of constant potential motors over motors which are not self-regulating, the latter have been largely superseded by the former.

Series Motors. The series wound motor is usually the type used on constant current circuits. As a constant current passes through the field and armature windings, the field strength and armature current will have a constant value and consequently the torque will be constant. Hence if the load is reduced the torque exerted remaining the same, the motor will speed up. If the load is entirely removed the speed becomes dangerously high, being much worse than when on a constant potential circuit for in the latter case the armature current is reduced as the speed increases. This increased speed can be prevented if the field is weakened, since the torque is then decreased, the armature current remaining the same.

The motor can be overloaded or held still without its being injured as the current is always the same, therefore no starting resistance is necessary and the throwing of a single switch starts or stops the motor.

Regulation. The usual method of changing the field strength to obtain constant speed is by cutting in or out turns of the field coils. The switch which does this is operated by some form of centrifugal governor, a slight increase of speed causing turns to be cut out and a slight decrease causing them to be inserted.

Another method is by rotation of the brushes. To reduce the field strength the brushes are rotated in a direction such that its magnetization will oppose that of the field magnets. To give a close regulation a comparatively large regulator is required.

MOTOR-GENERATORS.

Motor-generators, or dynamotors commonly called, are nearly synonymous terms applying to a combination of the *direct*

current generator and motor, for the purpose of either increasing or decreasing the voltage of distribution.

The motor which drives the generator, is usually shunt-wound and is connected on constant potential mains.

The simplest case is where the motor is directly connected to the generator, the E. M. F. generated by the dynamo being available for any purpose. Such an arrangement allows a considerable variation of E. M. F. This is usually accomplished by inserting varying resistances in the field circuit of the dynamo; weakening the field, of course decreasing the volts generated.

Where the ratio of transformation of voltage is definite, one field may be common to both motor and dynamo. The armature has independent motor and generator windings which have separate commutators. As the field is common to both the only method of varying the E. M. F. of the dynamo is by inserting resistances in either armature circuit or by shifting the brushes.

CALCULATION OF ELECTRIC MOTORS.

As a direct current dynamo may be used either as a generator or motor, it is evident that the principles of construction and calculation of direct current generators apply equally well to that of motors. Hence for the calculation of an electric motor it is only necessary to determine the corresponding values for a generator at the required speed, and to then proceed as in the calculation of a generator.

The question arises as to what power must the motor be calculated for when considered as a generator. We have seen that the losses in a dynamo are the electrical and the stray power. In a generator the output is equal to the total electrical energy less the *electrical* losses. In a motor the output is equal to the total electrical energy, which is the input, less *all* the losses, that is, the electrical together with the stray power loss. Hence, in making the calculations of a motor we must allow for the stray power loss and figure a generator which at the given speed has an electrical activity in watts equal to

$$\frac{\textit{motor output}}{\textit{gross efficiency}}.$$

Small motors up to 5 horse-power have a gross efficiency of from 80% to 85%, that of motors from 5 to 20 horse-power ranges from 85% to 90%, from 20 to 300 horse-power ranges from 90% to 95%, and motors of more than 300 horse-power have a gross efficiency slightly above 95%.

The E. M. F. for which the generator is to be calculated is the *counter* E. M. F. of the motor, being the E. M. F. generated by the motor at the given speed. This from the motor equation is equal in the case of the shunt motor to

$$e = E - Ir,$$

where e is the counter E. M. F., E the applied E. M. F., I the armature current, and r the armature resistance.

For the series motor

$$e = E - I(r + r_1),$$

where r_1 is the resistance of the field winding.

As the value of the resistances and current are not known, e must be estimated from values obtained by experience. The percentage of the applied E. M. F. which is lost in the armature, or in the case of the series motor in the armature and field winding, varies greatly according to the size of the machine. For shunt motors the per cent of the applied E. M. F. which is lost in the armature, is approximately as follows:

Up to ¼ H. P.	15 %
Up to 1½ H. P.	10 %
Up to 3 H. P.	8 %
Up to 7 H. P.	6 %
Up to 15 H. P.	5 %
Up to 35 H. P.	4 %
Up to 75 H. P.	3½%
Up to 150 H. P.	3 %

For motors of a greater output than 150 H. P. the per cent lost may be a little less. In the case of series motors the volts lost in the armature and field winding may be found by taking about twice the above percentage.

Having determined the electrical activity and the voltage for which the motor is to be calculated. the current capacity is found by dividing the former by the latter.

Example.—It is desired to construct a shunt motor which is to have an output of 5 H. P. at a speed of 1,200 revolutions per

minute, the motor to be run on a 110 volt circuit. Determine the values of the quantities to be used when calculated as a generator.

Solution.—For a 5 H. P. motor the gross efficiency is taken to be 85%. The watts generated by the armature are to be, therefore,

$$\frac{5 \times 746}{.85} = 4{,}400 \text{ watts (approx.)}.$$

Allowing 7% of the applied E. M. F. to be lost in the armature, the voltage to be generated, that is, the counter E. M. F., will be

$$110 \times .93 = 102 \text{ volts (approx.)}.$$

The current capacity will, therefore, be

$$\frac{4{,}400}{102} = 43 \text{ amperes (approx.)}.$$

Hence the armature is to be designed to generate a total E. M. F. of 102 volts, at a speed of 1,200 revolutions per minute, the current capacity to be 43 amperes.

Example.—Suppose we wish to design a series motor for a 220 volt circuit, the output to be 10 H. P. at 900 revolutions per minute. How is the machine to be designed?

Solution. — Supposing the gross efficiency to be 88% the number of watts to be generated is

$$\frac{10 \times 746}{.88} = 8{,}500 \text{ watts (approx.)}.$$

Allowing 12% of the applied E. M. F. to be lost in the armature and field winding the voltage to be generated is

$$220 \times .88 = 193 \text{ volts (approx.)}.$$

The current capacity is to be

$$\frac{8{,}500}{193} = 44 \text{ amperes (approx.)}.$$

Hence the armature is to be designed to generate a total E. M. F. of 193 volts at a speed of 900 revolutions per minute, the current capacity to be 44 amperes.

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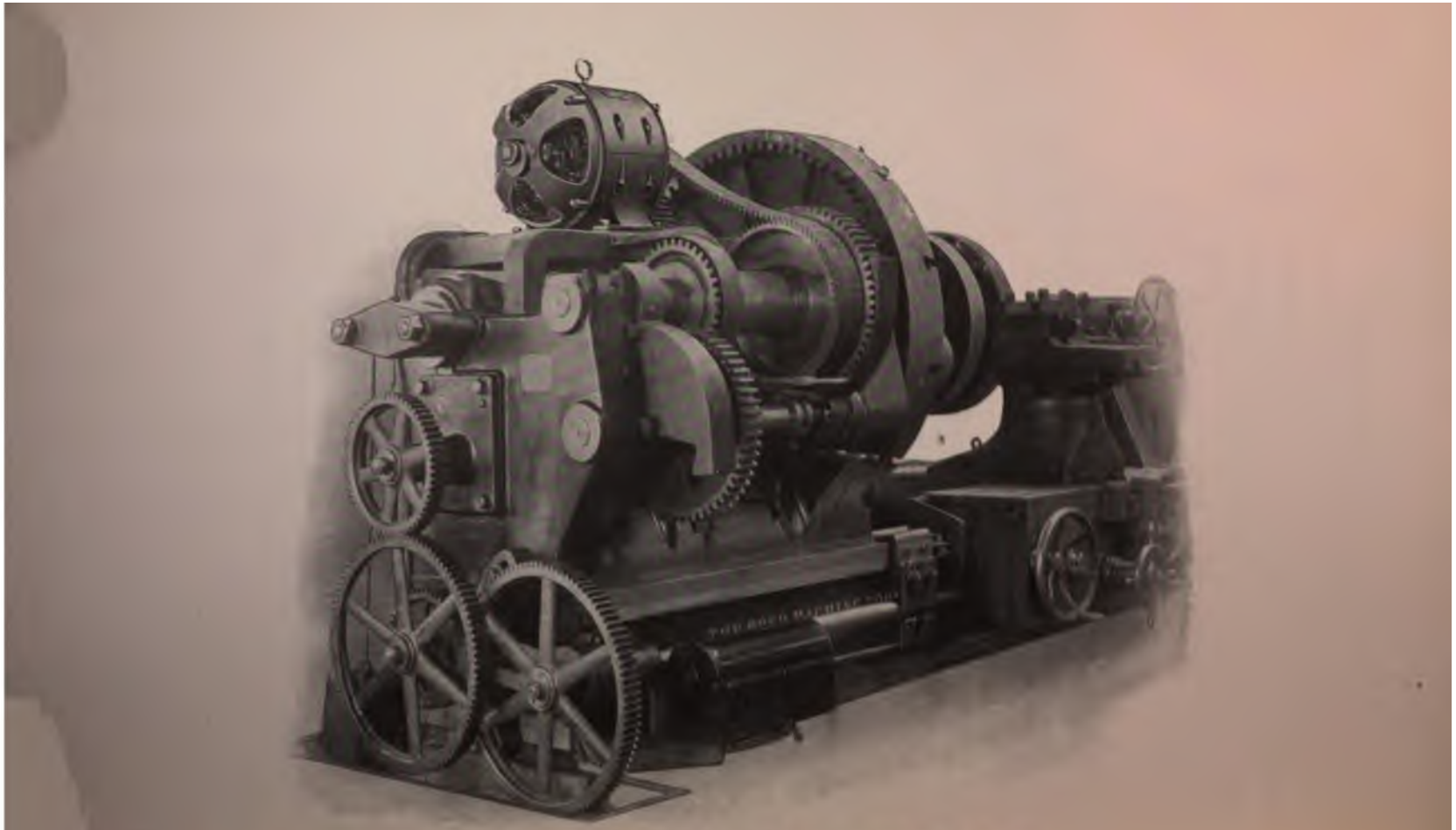


72-INCH LATHE DRIVEN BY 15 H.P. THOMPSON-RYAN MOTOR.
350-1750 Rev. per Minute.
Ridgway Dynamo and Engine Co.

ELECTRIC MOTORS IN MACHINE-SHOP SERVICE.*

I intend to consider the subject "electric motors in machine-shop service" from the standpoint of the shop engineer, whose one thought is economy in the broadest sense of the word. To such a man, the motor is but a single detail of the equipment—possibly one of the most important details, but only so when its relation to the problem as a whole, is understood. The development of alloy steels, permitting of cutting speeds from two to four times as great as was heretofore possible, requiring, in many instances, machines of new design; the introduction of the grinding machine, which is rapidly replacing the lathe for much finishing work; the milling machine; the electric motor as a means of driving; and types of management to assure efficient use of equipment, are among the most important factors requiring his attention.

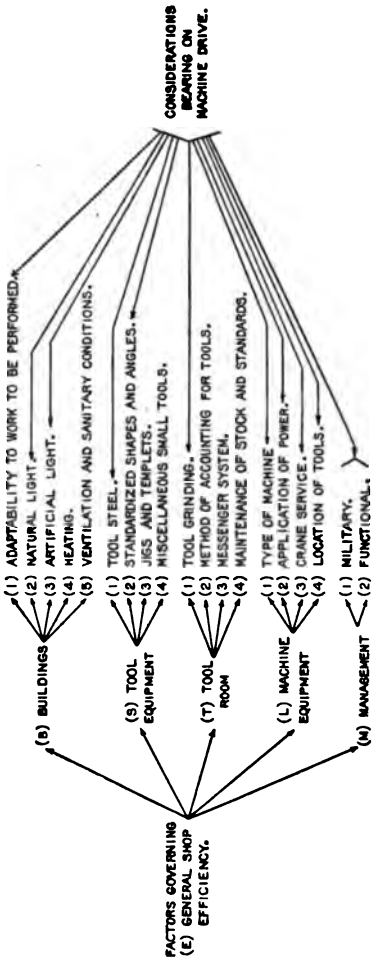
The manufacturers of electrical apparatus too often defeat their own ends by overenthusiasm, or rather, by extravagant claims that they cannot possibly substantiate. There is no use trying to convince the shop engineer that the words "motive drive" are synonymous with "low cost," for he knows that efficiency attained depends upon the co-operation of a multitude of things, and primarily the intelligence with which the equipment is handled. If, however, the possibilities of the motor drive are properly presented, he can appreciate them better than any one else, for they fill a definite need, the importance of which he will understand.

It is not necessary to dwell upon substantial progress recently made in shop practice, which has resulted, in many instances, in greatly increased output with consequent reduction in cost. I shall consider rather what is needed to increase efficiency in the average shop, where it is still extremely low, for even when adequate funds are provided for the purchase of new equipment, the end in view is often defeated through lack of proper insight in connection with its purchases, installation, and use.

At the same time electrical manufacturers have not made the progress that would have been the case had they possessed a

* This paper was presented before the International Electrical Congress of St. Louis, 1904, by Charles Day of the firm of Dodge & Day, Engineers, Philadelphia, Pa ; and is reprinted by special permission.

thorough understanding of shop requirements. Our experience has been confined largely to the installation and operation of electrical equipment under working conditions, therefore I shall treat the subject from this side, with the hope that I may bring more



Shop Considerations Bearing on Machine Drive.

Fig. 1.

clearly before the manufacturers the conditions they must meet, and at the same time aid the customer in specifying his requirements and securing results.

Generally speaking, the electric motor (either for group driving or individual operation of machines) is conceded as the proper

means of power distribution. My paper will deal with the subject under the following headings:

(1) Shop Requirements.
(2) Notes Concerning Motor-Drive Systems.
(3) Notes Concerning Different Makes of Apparatus.
(4) General Conclusions.

(1) SHOP REQUIREMENTS.[1]

My paper will only permit of a general outline of shop considerations bearing on the subject; these are illustrated in Fig. 1. Each factor must be carefully considered and, when treating the subject generally, certain assumptions made. For example, we are justified in assuming that the best tool steel should be used and design accordingly, while crane service and type of workmen are, on the other hand, matters depending on class of work handled and local conditions.

An intimate knowledge of shop practice is quite as necessary to the designer of electrical apparatus for machine *driving* as to the builder of the machine, and, while frequently difficult to show the direct bearing of the various features of management and methods upon a single factor, such as the one under consideration, the most useful conclusions can be drawn only by those familiar with the subject in detail. Improved systems of management are doing much to assure proper use of equipment, but in any event the need of explanation in connection with its operation should be eliminated to as great a degree as is possible. In other words, apparatus should primarily be designed to give satisfactory results in the hands of average workers. Where its adjustment and manipulation is dependent upon the operator, he must be fully considered

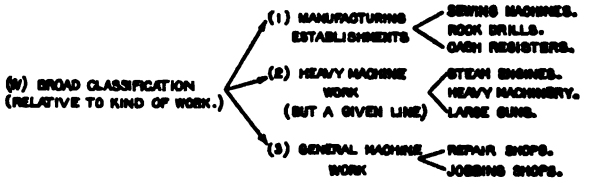
1. The words "machine" and "tool," as used in connection with machine-shop work, are very frequently ambiguous. I will use them in the following sense: *Machine.*—Definition (Standard Dictionary). Any combination of inanimate mechanism for *utilizing* or *applying power.* A construction for mechanical production or modification. Example Lathes, pneumatic drills, power shears, etc. *Machine Tool.*—This term is often confusing and need not be used in present paper. *Tool.*—Definition (Standard Dictionary). A *hand instrument.* Not a mechanism. Used directly for production. Examples.—Chisel, hammer, saw, etc.

Tools for removing metals will be further subdivided as follows: Cutters, millers, drills, etc.

in the design, but when attention is required for inspection at intervals only, the personal equation does not enter into the problem to as great an extent. Lathe and elevator drives illustrate the two cases.

If cuts are of long duration, the cutting speed can readily be determined by experiment, but this is not practical in the run of machine-shop work. The determination of cutting speed for miscellaneous work is a difficult matter, and must be given special study in each case, every means toward uniformity of product being resorted to.

The drive is but a detail of the machine. We should aim at a harmonious whole, not combining an efficient drive with an out-of-date tool. The motor-driven tool of the future should not be considered a combination, but a *unit* suited to certain specific ends. The motor-drive problem is essentially a matter for the machine



General Machine Shop Classification.

Fig. 2.

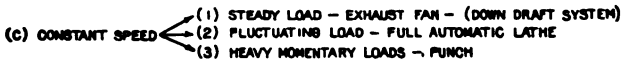
builder to settle, and when a machine is purchased, the customer should have the assurance *that the drive has been given the same care in design and construction as any other part of the machine, and need not be considered as a distinct issue.*

Machine shops may be broadly classified according to character of output as follows:

Shops of the first class can be laid out in every detail with regard to a definite need. Machines are purchased to do just one job, and frequently it pays to design special machinery for such duty. After it is properly adjusted for the character of material to be worked and for the cutters, no changes are required until better methods or facilities are developed. Here, as far as the drive is concerned, we find the simplest conditions. Usually constant speed with adequate power suits the case.

In shops classified under the second heading, little opportunity for duplication, in the sense just considered, exists. Machines

must handle a variety of work, and even those purchased for specific operations are usually suited for other purposes so they may be kept busy the greater part of the time. Variation in size of work, material and cutters, demands an adjustable speed drive

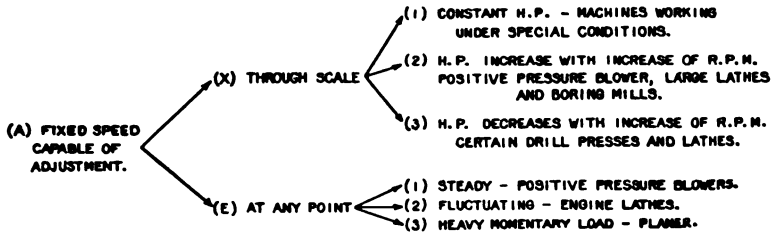

(C) CONSTANT SPEED
(1) STEADY LOAD – EXHAUST FAN – (DOWN DRAFT SYSTEM)
(2) FLUCTUATING LOAD – FULL AUTOMATIC LATHE
(3) HEAVY MOMENTARY LOADS – PUNCH

Character of Load for Constant Speed Drive.

Fig. 3.

together with change feeds, if most economical results are desired. This is true to a still greater degree for machines in the third class.

The drive requirements from a consideration of work to be performed can be further analyzed as shown below:


(A) FIXED SPEED CAPABLE OF ADJUSTMENT.
(X) THROUGH SCALE
(1) CONSTANT H.P. – MACHINES WORKING UNDER SPECIAL CONDITIONS.
(2) H.P. INCREASE WITH INCREASE OF R.P.M. POSITIVE PRESSURE BLOWER, LARGE LATHES AND BORING MILLS.
(3) H.P. DECREASES WITH INCREASE OF R.P.M. CERTAIN DRILL PRESSES AND LATHES.
(E) AT ANY POINT
(1) STEADY – POSITIVE PRESSURE BLOWERS.
(2) FLUCTUATING – ENGINE LATHES.
(3) HEAVY MOMENTARY LOAD – PLANER.

Character of Load for Adjustable Speed Drive.

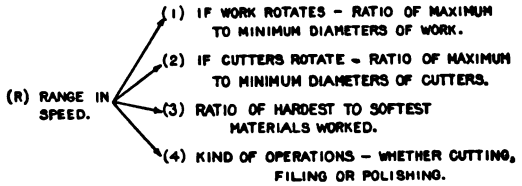
Fig. 4.

Figs. 3 and 4 relate to *character* of load. Figs. 5 and 6 are a further analysis of adjustable speed drive, for machines using cutters, giving details that should determine *range* and *number* of speeds.

Adjustable speed[2] may be desirable on grinding machines also, and in this case will depend on ratio of maximum to minimum wheel diameters and other matters that must be considered separately in individual cases.

2. The words "variable speed" are now generally used for describing motors adapted for individual operation of machines, but to distinguish from the crane motor, for example, which is truly the variable-speed type, I shall use the words "adjustable speed" as describing a fixed speed capable of adjustment over a given range. Variable-speed motors are used principally for railway and crane service where the load is intermittent and torque variable. Direct-current apparatus has been developed to give such thoroughly satisfactory results for this duty that I shall not consider it other than in its relation to the general machine-shop problem.

Machines for punching and shearing, while usually arranged for constant speed, frequently require an adjustable-speed drive. For example, assume a punch operating at 28 strokes per minute. The operator may have work of such a character that he can easily punch a hole each stroke, while in another case, due to heavier sheets or greater accuracy required, he is compelled to skip every other stroke, punching but 14 holes a minute, while if the machine


(R) RANGE IN SPEED.
(1) IF WORK ROTATES - RATIO OF MAXIMUM TO MINIMUM DIAMETERS OF WORK.
(2) IF CUTTERS ROTATE - RATIO OF MAXIMUM TO MINIMUM DIAMETERS OF CUTTERS.
(3) RATIO OF HARDEST TO SOFTEST MATERIALS WORKED.
(4) KIND OF OPERATIONS - WHETHER CUTTING, FILING OR POLISHING.

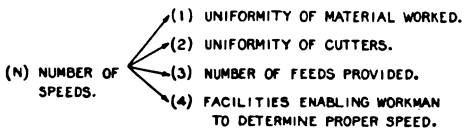
Factors That Influence Range of Speed.

Fig. 5.

would permit he could readily do 28. Such a saving on this class of machinery usually yields a large actual return as the time required for setting up or making ready is, as a rule, small.

The *amount* of horse-power required for machines of different types depends on the factors given in Fig. 7.

I have given the principal items to consider when designing or selecting machine drives, but to more fully explain the line of


(N) NUMBER OF SPEEDS.
(1) UNIFORMITY OF MATERIAL WORKED.
(2) UNIFORMITY OF CUTTERS.
(3) NUMBER OF FEEDS PROVIDED.
(4) FACILITIES ENABLING WORKMAN TO DETERMINE PROPER SPEED.

Factors That Influence Number of Speeds.

Fig. 6.

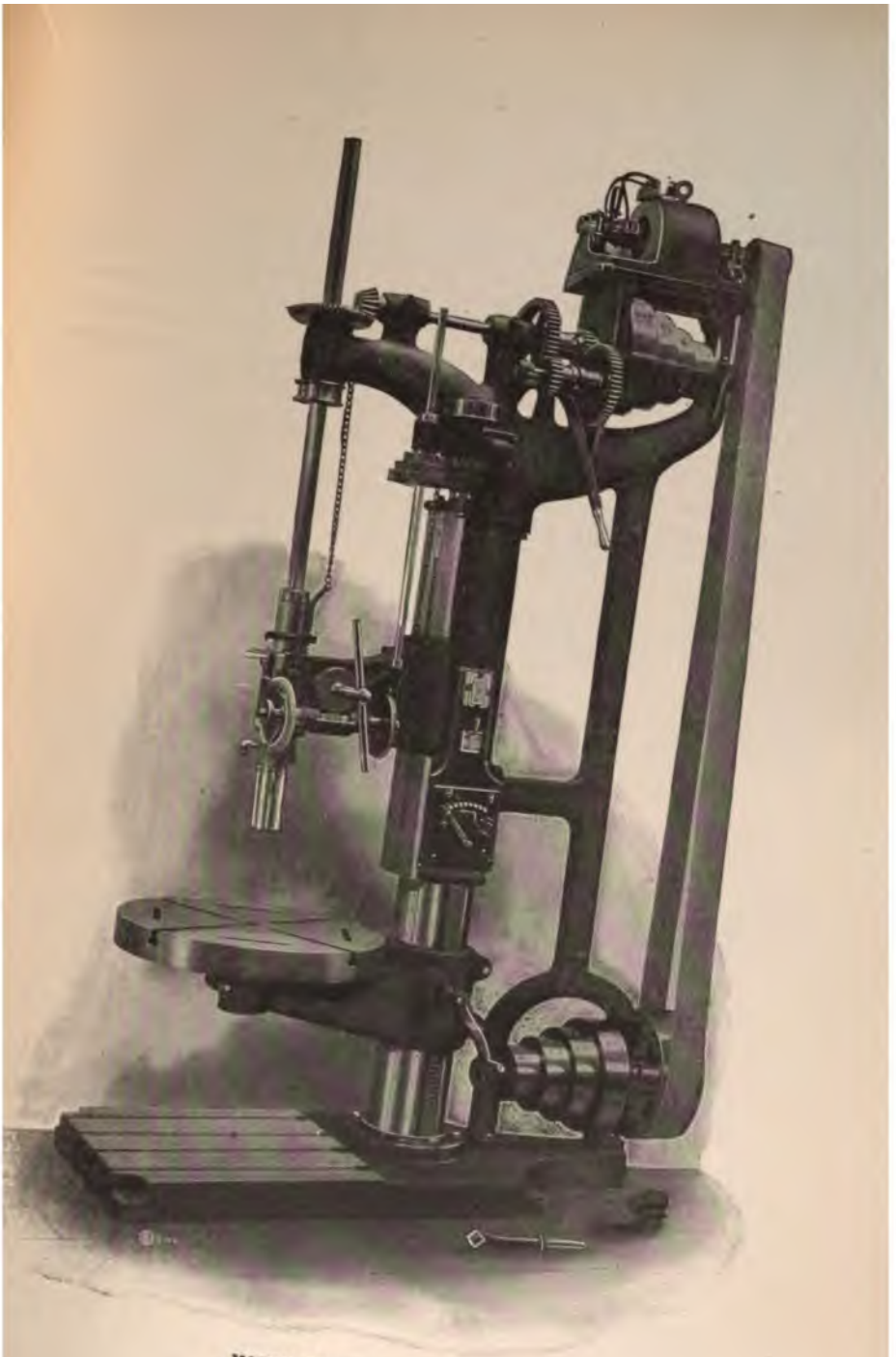
reasoning that should be followed, I shall assume definite conditions, and consider the equipment needed to fulfill them.

EXAMPLE.

LATHE..... for general work in shop of A. ———. B. ———. Company, manufacturer of air compressors.

General features of this plant and its organization that influence type of drive (see Fig. 1).

E.B.—1. The machine under consideration is to run in an old plant, hence no saving in cost of buildings could be effected by type of drive.



MOTOR-DRIVEN DRILL.
The Hamilton Machine Tool Co.

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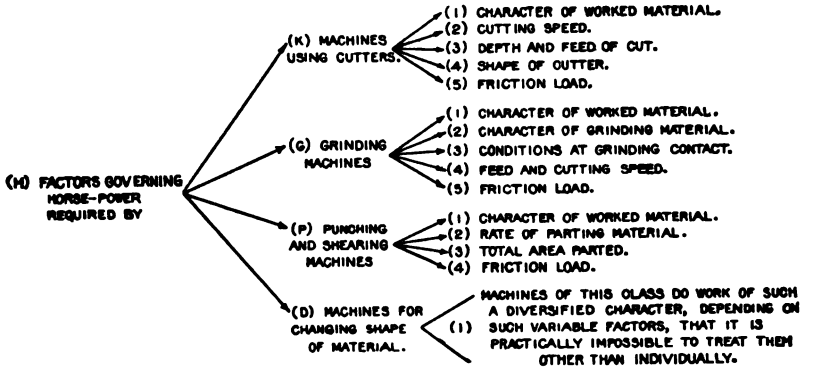
E. B.—2. The natural light at point where lathe is to be located is very poor, and it is important not to obstruct it any more than absolutely necessary.

E. B.—3. Artificial light has in the past been supplied by independent company, but they desire to install a power plant that will take care of this feature as well as power. It is desirable to depend largely upon general illumination by arc lamps with incandescent lights for detail work.

E. S.—1-2, and E. T.—1. For roughing work the best alloy steels, forged, treated, and maintained by special department, assuring uniformity and high efficiency, will be used.

E. L.—1, 2, 3, 4. Character of work necessitates constant use of power crane, making overhead belting and fixtures objectionable and difficult to provide for on account of location in main bay of shop. As cost of power in this plant amounts to less than 3 per cent of total cost of product, it is not a determining factor in character of drive.


(H) FACTORS GOVERNING HORSE-POWER REQUIRED BY
(K) MACHINES USING CUTTERS.
(1) CHARACTER OF WORKED MATERIAL.
(2) CUTTING SPEED.
(3) DEPTH AND FEED OF CUT.
(4) SHAPE OF CUTTER.
(5) FRICTION LOAD.
(G) GRINDING MACHINES
(1) CHARACTER OF WORKED MATERIAL.
(2) CHARACTER OF GRINDING MATERIAL.
(3) CONDITIONS AT GRINDING CONTACT.
(4) FEED AND CUTTING SPEED.
(5) FRICTION LOAD.
(P) PUNCHING AND SHEARING MACHINES
(1) CHARACTER OF WORKED MATERIAL.
(2) RATE OF PARTING MATERIAL.
(3) TOTAL AREA PARTED.
(4) FRICTION LOAD.
(D) MACHINES FOR CHANGING SHAPE OF MATERIAL.
(1) MACHINES OF THIS CLASS DO WORK OF SUCH A DIVERSIFIED CHARACTER, DEPENDING ON SUCH VARIABLE FACTORS, THAT IT IS PRACTICALLY IMPOSSIBLE TO TREAT THEM OTHER THAN INDIVIDUALLY.

Factors Governing Horse-Power Required for Different Types of Machines.

Fig. 7.

E. M.—2. The type of management being introduced at this plant should ultimately assure intelligent direction of work and proper use of equipment.

Referring to Fig. 2:

We find that this shop will come under the class indicated by the symbol *W-2.*

Referring to Fig. 4:

(A)—X—1—F—2. Majority of work (probably 80 per cent) will be steel and gray-iron castings between 18 ins. and 48 ins. diameter. Maximum conditions call for removal of same amount of metal between these limits, and approximately constant cutting speed. Maximum horsepower requirements are consequently constant through the range, but subject to fluctuations at any one point below the said maximum.

Referring to Fig. 5:

R—1. At times it will be necessary to machine work as small as 10 ins. diameter, or as large as 60 ins. diameter; consequently a range in speed of 5 : 1 would be required for this purpose.

R—2. Cutters will always be stationary.

R—3. The ratio of hardest to softest material required by specification will be approximately 2 : 1. This will increase the necessary speed range to 10 : 1.

R—4. The majority of work will be roughing and finishing with cutters. Some filing and finishing with emery cloth will, however, be necessary, and for this purpose experience would dictate a cutting speed of 150 ft. per minute on 10 ins. diameter It will be necessary to provide a cutting speed of 15 ft. per minute on the largest diameter on account of the frail character and difficulty of driving some of the castings to be machined. Total range of speed is determined by limiting conditions of a cutting speed of 15 ft. per minute on 60-in. work and 150 ft. per minute on 10-in. work. I have purposely chosen these extreme conditions to better illustrate my point. In practice a 60-in. lathe is seldom required to run at 57 r.p.m.

$$\frac{\frac{150}{10 \times 8.14}}{12} = 57.3 \text{ r.p.m.}$$

$$\frac{\frac{15}{60 \times 8.14}}{12} = .95 \text{ r.p.m.}$$

Consequently, for all practical purposes, the face plate of the lathe should run from one revolution per minute to 57 revolutions per minute.

Referring to Fig. 6:

N—1. It was stated above that the character of material would vary in the proportion of 2 : 1, this being a requirement of the products manufactured. Uniformity of material, or how nearly the requirements can be attained under shop conditions, is one of the factors influencing the number of face-plate speeds.

A fully-equipped laboratory, under the direction of an able chemist, who has entire charge of the cupolas and Bessemer steel converters, assures a much more uniform product in the plant in question than is usually the case. A great deal of experiment and investigation will be necessary however, before we can make definite assertions in this direction, but castings from the same pattern should not vary more than 20 per cent.

N—2. Cutter of the character indicated above (E.S.—1) should not vary in efficiency more than 10 per cent.

N—3. The full consideration of this point involves an understanding of the laws governing speed, feed, and cut for various materials. It will not be practical to include here [illegible] this detail. Hundreds of

tons of steel and cast iron have been cut up to determine these relations, and constant experiment is necessary to keep abreast of rapid improvements. I will only say that it is quite as necessary to provide an adequate number of feeds as it is spindle-speeds, and in fact a limited number of either one of these factors will give efficient results provided a very close regulation can be had on the other.

In the present instance it was not considered advisable to specify changes to the standard feeding mechanism, as this feature had been well taken care of by the builder.

N—4. As the operation of the machine is ultimately governed by the facilities at the disposal of the machinist who runs it, it is absolutely essential that this point be given most careful study. It involves practically every feature of shop system and management, and it is only under such systems as that developed by Mr. Fred W. Taylor, of which functional foremanship is but a single detail, that the conditions, as outlined above, can be fulfilled. It necessitates that the operator of the machine be informed as to the character of the material, efficiency of the cutter, proper cutting speed in consideration of duration of cut, and many other equally important factors.

So it will be seen that we cannot arrive at any data which would enable us to specify definitely the number of spindle-speeds required. Our conclusions must necessarily be based principally on experience in shop practice, and for this reason engineers differ widely in their views. For the example under consideration, speeds increasing in increments of 15 per cent are, in our estimation, quite as close as can be used to advantage. It is well, however, to err on the safe side, providing too many speeds rather than too few.

Referring to Fig. 7:

H. K.—1, 2, 3, 4. Maximum permissible cutting speed on steel castings will be 60 ft. per minute; on gray-iron castings 60 ft. per minute (determined by actual requirements on a large variety of work). Maximum cut, cast-steel, $\frac{3}{8}$ in. deep, $\frac{1}{16}$ in. feed; gray-iron, $\frac{3}{8}$ in. deep, $\frac{1}{16}$ in. feed. (These conditions are established by character of work.)

The experiments conducted to determine the laws governing speed, feed, and depth of cut, for various materials referred to above (*N—3*) have been made available for purposes of design by means of slide rules, based on the derived empirical formulæ.

For the depth of cut and feed under consideration (cast-steel), the calculated pressure on the tool would be: 5,550, or horse-power required $= \frac{5550 \times 60}{33{,}000} = 10.1$ hp.

H. K.—5. The friction load can only be arrived at through experience and depends not only on the machine, but character and method of driving work. Experimental data on machines quite similar to the one under consideration would indicate 3 horse-power through the entire range as sufficient to allow for this purpose.

These conditions are plotted in Fig. 8. It will be noticed that the horse-power falls off on either side of the working part of the scale.

While it is easy to theorize as to the horse-power required for work of various diameters, in actual practice the conditions are about as I have shown. It must be borne in mind that the machine under consideration should be primarily adapted for the majority of work that it will handle. We have assumed that 80 per cent of this will be between 18 ins. and 48 ins. in diameter, so that work outside of these limits is the exception. On small work, such as would be handled, there is not likely to be opportunity for as heavy roughing cuts, and castings over 48 ins. in diameter cannot be swung over the carriage, nor would it be good policy to aim at high efficiency at this point for the additional cost would not be justified by the saving effected on such a small fraction of the total output.

As the horse-power between the working limits shown above was figured for the maximum cutting speed of 60 ft. per minute, we can plot a relation between revolutions per minute and horse-power. (See Fig. 9.) The selection of electrical equipment for this lathe will be taken up further on.

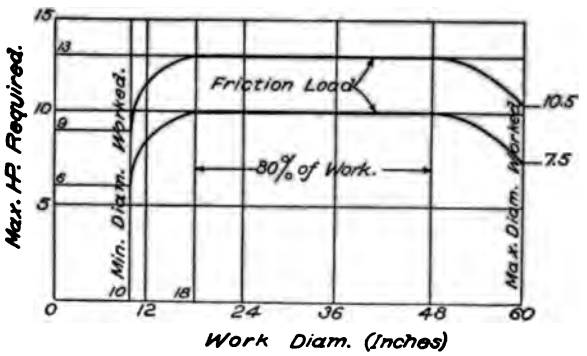


Fig. 8.

The analysis of conditions presented above is, as was stated, essentially a problem for the machine builder to work out—in other words, the electrical companies should look to him for general specifications covering motors and controllers.

When equipping machines of old design with motor drive, or remodeling them to better their efficiency, each one should be considered separately with regard to the special line of work it handles. As manufacturing becomes more specialized it will be possible for the builder of machines to design with more intelligence, for he can then treat a type as we have treated an individual.

To avoid repetition, I will assume the following conclusions have been established.

(1) Machines of present design of comparatively small work, requiring constant-speed drive should, in most instances, be grouped

and operated from motor-driven line shafts. Specifications for new machines for such duty should be made with a view to special requirements. Indirect savings in one plant may much more than offset additional cost of constant-speed motor on each machine, while this would not be true in another.

(2) For group driving, both direct- and alternating-current motors give thoroughly satisfactory results. In either instance, if properly installed, repairs should not be an important feature. In

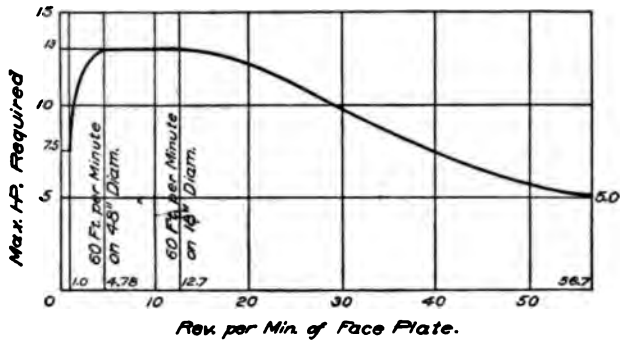


Fig. 9.

certain industries—the textile mills for example—the induction motor has decided advantages on account of close-speed regulation with varying loads and lessened fire risk, but for machine shops these features are unimportant.

(3) Mechanical means of speed control, including step cone pulley and variable-speed countershafts, while suited for certain specific cases, do not meet the general requirements of machine drive. An attempt to obtain the necessary speeds by gearing, for example, is not only costly (if a sufficient number of changes are provided), but inefficient, in that as a rule, the machinery must be stopped to change from one speed to another, and cannot be controlled from an independent point.

(4) For adjustable speed work, direct-current motors only give satisfactory results at the present time. It is not practical by this means to use a range greater than 6 to 1, while in the majority of cases 3 to 1 gives the most economical results. In other words, in most instances, it is necessary to resort to a combination of mechanical and electrical control, the disadvantages of

each being largely eliminated by this means. For example, even where machines are handling a very general line of work, the greater part of it will be covered by a range of 3 to 1, so that if this amount is obtained electrically, gear changes will be seldom necessary, and at the same time a comparatively inexpensive motor required. Consequently the lathe requirements specified above are of quite as much value to the man who designs the mechanical features of the machine as the one who furnishes the electrical apparatus.

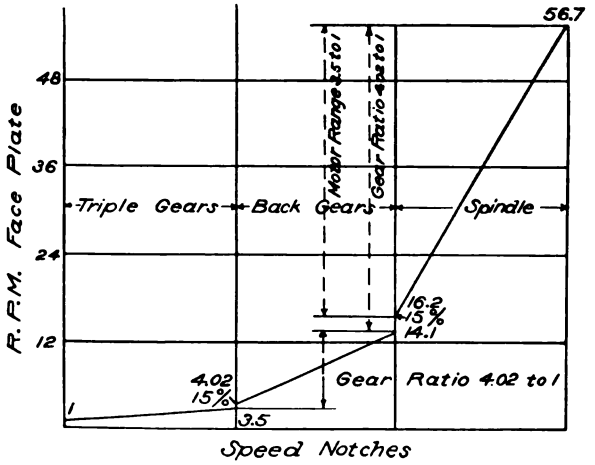


Fig. 10.

(5) Long transmission lines may make alternating-current desirable, and, for certain extended plants, the best results can be obtained by its use, together with motor-generator for direct-current variable-speed motors. If, however, but one kind of current will be available, decision should be largely governed by number of individual drives required. In many instances, while group drives may be desirable at the start, new equipment should be purchased with individual motors for the sake of adjustable speed and ease of control.

Returning to the 60-in. lathe considered above, the total speed range of 57 to 1 can be covered by the usual triple gear arrangement, with the resulting ratios shown on the chart. The range in motor speed, of 3.5 to 1, is quite practical and can be taken care of by any one of the systems referred to above.

I shall not dwell upon the strictly mechanical details of the drive, rather assuming that this part of the work is properly taken care of, but pass on to a consideration of the motor-drive systems.

(2) NOTES ON MOTOR-DRIVE SYSTEMS.

Systems now on the market for obtaining adjustable speed by means of motor drive, and advocated by prominent manufacturers, are given below:

(1) Field weakening only

(2) Double commutator motor combined with field weakening.

(3) Edison three-wire system combined with field weakening.

(4) Unbalanced three-wire system combined with field weakening.

(5) Four-wire multiple-voltage system combined with field weakening.

There are two classes of purchasers, with widely differing requirements, and to whom different systems appeal:

(1) The customer who buys motors for his own use to equip machines already in operation, or special machinery which must be given individual consideration.

(2) The customer who buys for an unknown third party. The builder of machines, for example, who manufactures his product without any knowledge as to whom the purchaser may be, and consequently must design equipments that will meet conditions existing in plants where his product is solicited.

The electrical manufacturers have been slow in realizing this almost self-evident classification. The very essence of modern manufacturing consists in specialization, as it is only in this way that cost can be reduced to a minimum. Such establishments must be classified under the second division referred to above, and the product considered as a *type*, while in the first class given machines or given establishments can be treated separately.

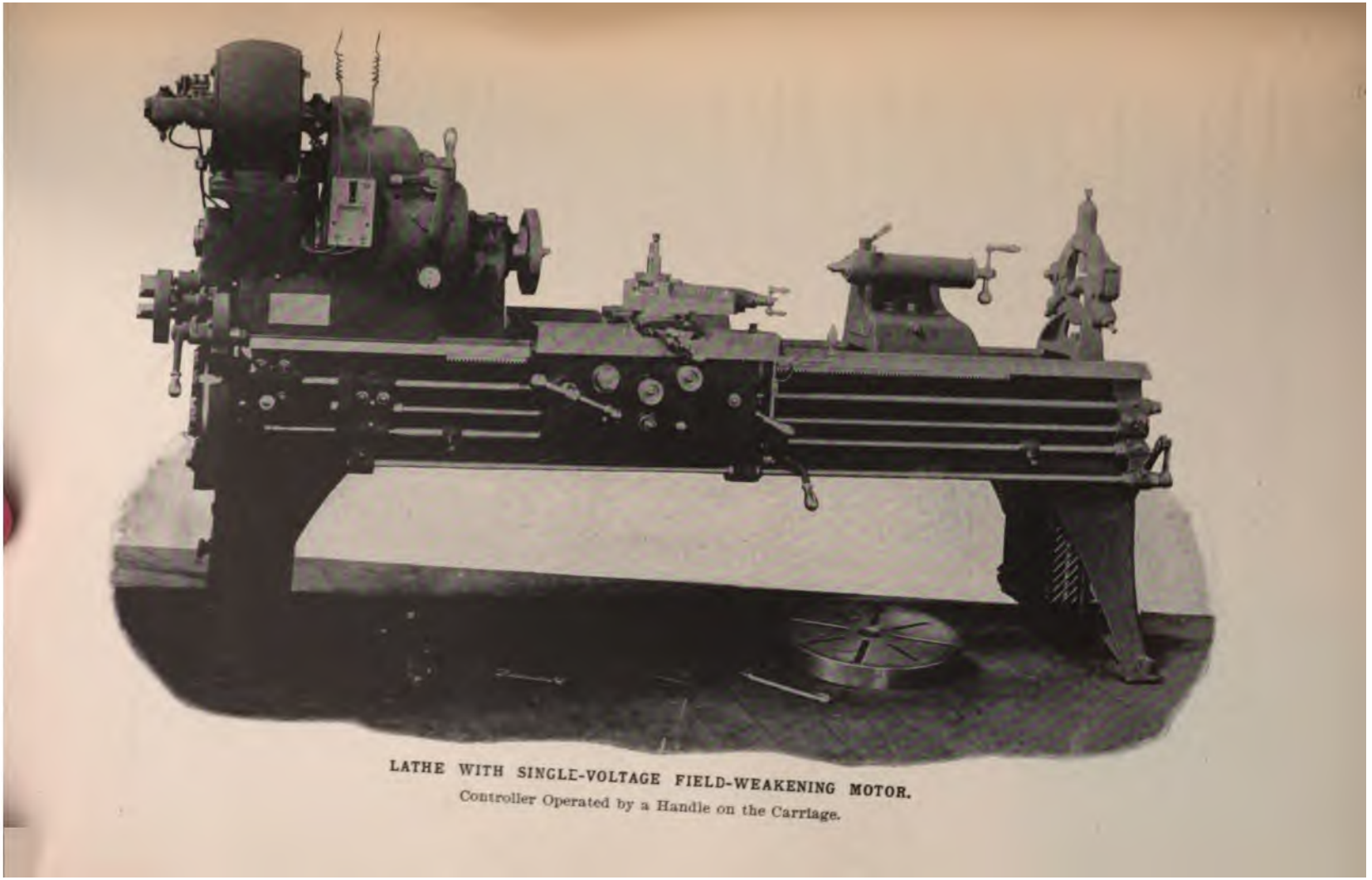
Conditions in the past have in either case demanded a separate consideration of drive for practically every customer, on account of special character and numerous types of motor-drive equipment, but substantial progress, as far as the machine builders are concerned, will not be made until their product is manufactured complete in every essential. This means the adoption of a motor that

can be operated on 110 or 220 volts, direct current, as one of these is not only found in nearly every large establishment, where it is used for cranes and lighting, but in many of the small shops.

The three- and four-wire systems, on the other hand, have been installed by a very small percentage of the shops who are, from time to time, purchasing new equipments, hence for commercial reasons such apparatus does not appeal to machine builders. It may, however, possess distinct advantages to purchasers of the first class who contemplate the motor equipment of an entire shop, either at once or as conditions demand. As they can exercise the greatest freedom in selection of equipment for motor drive, I shall consider the systems enumerated above from their standpoint. It will then be a comparatively simple matter to apply these conclusions to the more special conditions which must be met by the machine builders.

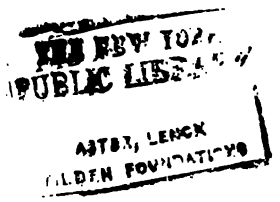
All customers, unless they employ consulting engineers, are called upon to decide themselves upon the system to adopt, and, as their experience does not, as a rule, cover the details of electrical engineering, they must depend largely on the statements put forward by electrical companies.

There is no doubt that the manufacturers in many instances have taken advantage of the special character of machine work to rate their motors in a way that is very deceptive. The words "full load" are almost universally abused, and as there is no standard specification adhered to, the only safe basis for comparison is through a knowledge of the weight and maximum speed for a given horse-power through a given range, with the understanding that a specified overload must be carried at any point for a certain time. Such an analysis would, according to the views of the various builders, give at least an intelligent idea of the equipment required to fill a definite need, but in a number of instances our experience has indicated that claims made by leading manufacturers have not been fulfilled in actual test. Machine-tool duty unquestionably permits of a different basis of rating from constant horse-power work in much the same way that street railway motors are rated on a basis of their own, but when one manufacturer adheres strictly to a rating of present standard, and another departs from it without the knowledge of the customer, the latter is likely



LATHE WITH SINGLE-VOLTAGE FIELD-WEAKENING MOTOR.

Controller Operated by a Handle on the Carriage.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to be comparing bids on two radically different equipments. This we have repeatedly found to be the case. We feel that this matter should be given careful consideration by such a body as the American Institute of Electrical Engineers and a definite understanding arrived at.

I shall assume general familiarity with the systems under consideration. In general, a motor for a given maximum speed and a given range, to deliver a given horse-power through this range, will be at least as large when operated by field weakening only, as when a combination of either two or more voltages with field weakening is adopted. Unless the motor is specially designed for field weakening, it will be larger than in the latter case. We have been unable to obtain any satisfactory data from the engineering departments of electrical manufacturers concerning variation of horse-power with field strength, so prefer to base our conclusions upon tests which we have conducted in connection with work for various clients.

As the cost of variable-speed motors and auxiliary power transmission equipment, such as chain or gears, is in proportion to the speed at which it operates, we should see that the latter is as high as is consistent with the various engineering considerations. A number of the manufacturers of motors do not give sufficient thought to the adaptation of motor speeds to available means of transmitting power to the machine. There are three methods in common use, namely: leather belts, gears (including worm and spiral gearing) and chain. While the great flexibility of the belt, in relieving the machine of sudden jar, has distinct advantages in certain instances, gears and chain are used in the majority of cases for individual drive.

(1) FIELD WEAKENING (WITH A SINGLE VOLTAGE).

A number of manufacturers have recently placed on the market motors designed to run on a single voltage, but that may be varied in speed by means of field weakening over a range, in some cases, as high as 6 to 1. Until recently, ranges as great as the above have not been considered practicable and our tests of motors of various makes have indicated that in this respect much can be accomplished through careful motor design. Manufacturers that

adhere to the simple shunt type do not advocate, except for speci work, a range exceeding 4 to 1, while others who have adopte either additional poles or special windings claim to have elim nated the difficulties usually encountered, and are prepared to fu nish motors giving any variation desired. These types, howeve have not been in operation a sufficient length of time to enable u to confirm their statements.

We have found that customers are frequently misled concern ing the size of frame required for a given duty for motors operat ing on this system. As the horse-power that can be develope with a given frame is in proportion to the speed of the armature it is necessary to use, for a range of 4 to 1, a motor frame rated a least four times as large as the power required if practical speed are not to be exceeded. Even such a frame will not, in most cases make it possible to rate the motor as liberally as is the case with standard constant-speed apparatus, as the exceptionally strong field required is likely to cause heating at the slow speed, and at the high speed the weakened field will cause poor commutation.

We have not yet experimented with a motor of this type that would operate continuously under the full-load current at its highest speed without giving some trouble at the commutator. It is true, as was stated above, that such conditions would rarely be met in the machine shop, but to purchase with intelligence it is necessary to know how much manufacturers depend on this fact. Motors with a range of 3 to 1 have already been successfully applied to machines requiring a comparatively small amount of power, although, as will be pointed out later, the apparatus has not been perfected as fully as is the case with other systems.

If the lathe considered above be equipped with apparatus operating on this system, the relation between motor horse-power and that required by the machine, shown in Fig. 11, should fulfill the conditions satisfactorily, as the upper curve is drawn through maximum values, and when they are reached the overload on the motor would only be 30 per cent.

Referring to the dimensions and ratings furnished by one of the manufacturers, whose apparatus has shown up very favorably under test, we find that a motor weighing 1,615 lbs. will deliver 10 horse-power between a range of 350 r.p.m. and 1,050 r.p.m., or

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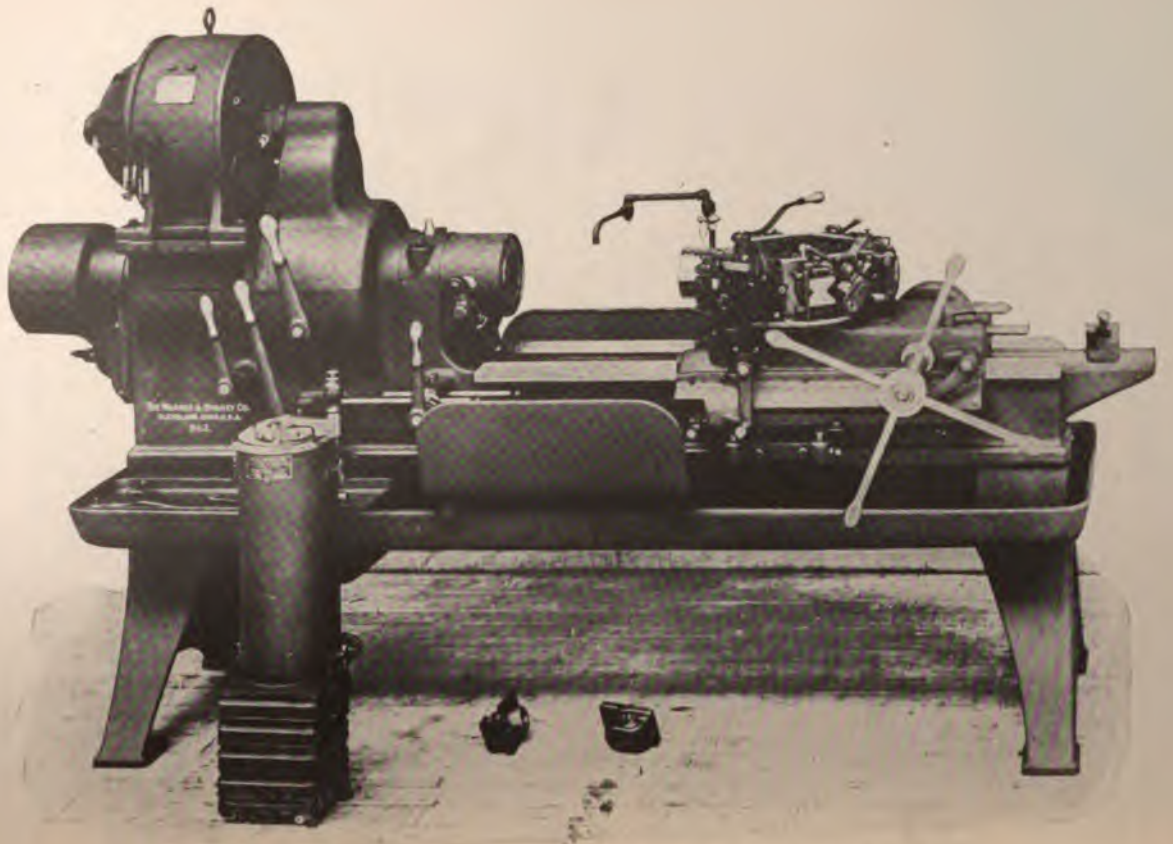


WARNER AND SWASEY TURRET LATHE WITH BALANCED THREE-WIRE EQUIPMENT.

Controller within Easy Reach of Operator.

one weighing 2,300 lbs. will deliver 10 horse-power between 225 r.p.m. and 900 r.p.m. We recommend the use of the last frame, as satisfactory commutation should be assured by the smaller speed range, namely, 225 r.p.m. to 787 r.p.m.

(2) DOUBLE COMMUTATOR MOTOR (COMBINED WITH FIELD WEAKENING).

The additional cost of the double commutator motor, together with the maintenance of two commutators instead of one, are objections to this system that, in our estimation, offset its advantages for other than special cases.

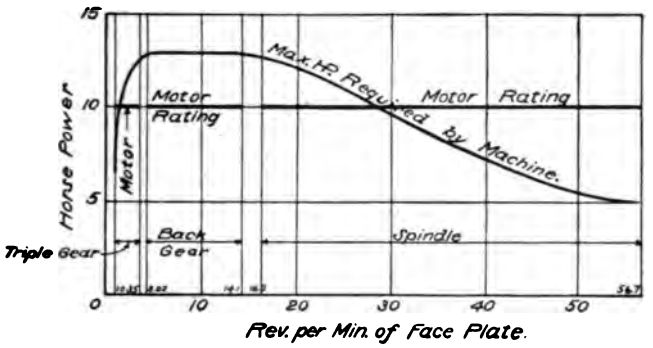


Fig. 11.

(3) EDISON THREE-WIRE SYSTEM.

The combination of the Edison three-wire system with field weakening permits of a range of 4 to 1, with but 100 per cent increase in speed by the latter means, and, consequently, eliminates commutator troubles to a marked extent.

The balanced three-wire system has been adopted quite generally in the past for lighting purposes, and may be obtained either by means of standard generator, together with a separate balancer, or by providing the former with slip rings connected to an autotransformer from the middle point of which the neutral is taken. The latter arrangement is advocated by manufacturers of this apparatus.

The selection of motor to operate on three-wire system for the 60-in. lathe should be based on curves shown in Fig. 12. The same assumptions are made regarding overload as in the former case.

The motor required for these conditions, according to one of the principal advocates of the Edison three-wire system, would weigh 2,600 lbs. and operate from 220 r.p.m. to 880 r.p.m.

(4) THE UNBALANCED THREE-WIRE SYSTEM.

The unbalanced three-wire system was developed to give, with a minimum size motor, a range somewhat greater than 6 to 1.

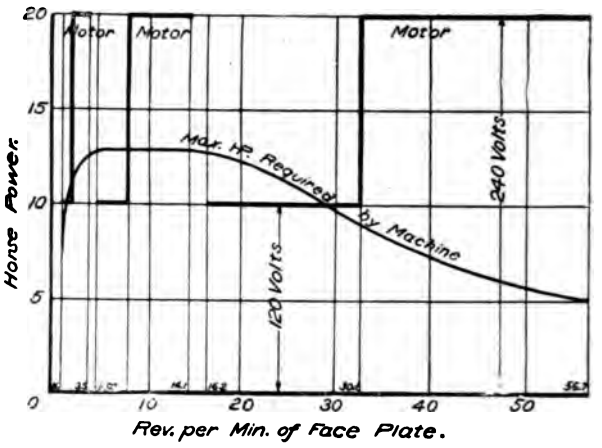


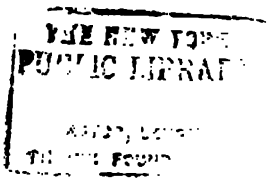
Fig. 12.

For a range of 4 to 1, or under, it has no advantage over the balanced three-wire system, nor does it possess the several good features of the one last named.

(5) FOUR-WIRE MULTIPLE VOLTAGE SYSTEMS.

The principal advantage of the multiple-voltage system is that absolutely standard motors (the same as are used for constant-speed duty) are used with perfectly satisfactory results. This is not true of any of the other systems. Motors designed to operate on a three-wire system must run with full field, full voltage at about half the speed of a constant-speed motor for the same duty, therefore cannot be economically used for the latter purpose. This is true to a still greater degree for motors designed to give a wide range of speed by means of field weakening only.

The maximum range in speed obtainable by the system under consideration depends upon the voltages adopted and the amount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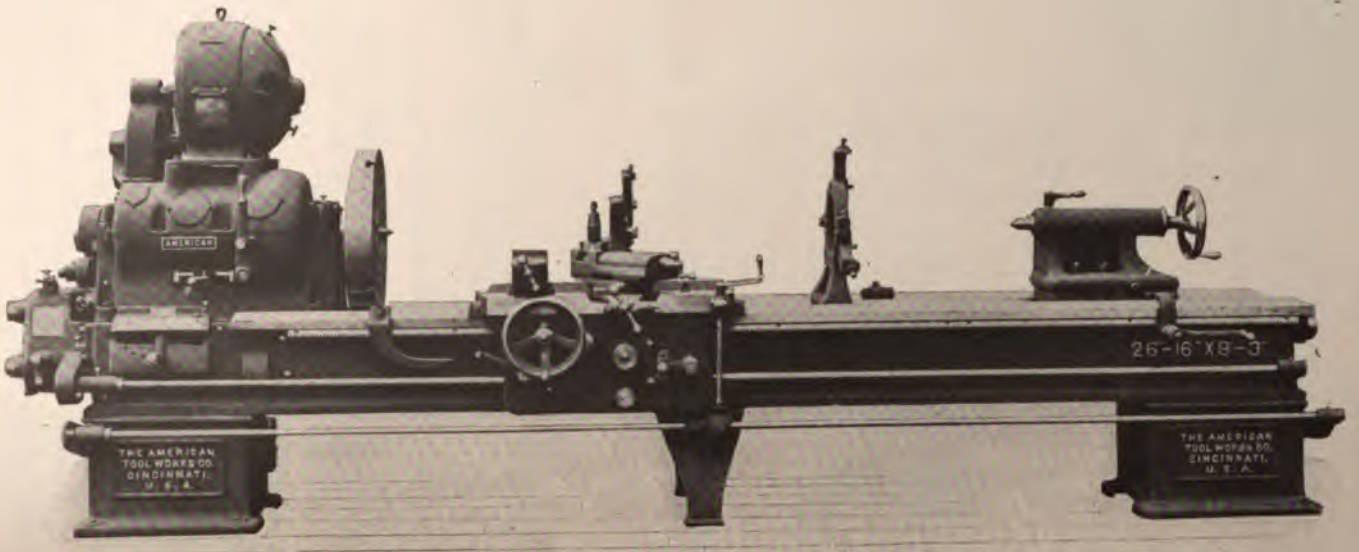


LATHE EQUIPPED WITH CROCKER-WHEELER MULTIPLE-VOLTAGE APPARATUS.

Controller Arranged so that the Operator Can Start, Stop, and Obtain Any Spindle Speed Within Range of Motor, without Leaving His Work.

the field is weakened, but for purposes of economy, except where constant torque is required, the working scale is usually confined to the higher voltages. The lower voltages, while used chiefly for starting, prove of great assistance at times for setting up work.

The two systems which have been advocated differ in that one requires an arithmetical series of voltages, and the other a geometrical series. In either case a balancer, or specially designed generator, is required to give the voltage referred to and four wires employed for distribution. These two features are frequently cited as disadvantages that more than offset the good points of this

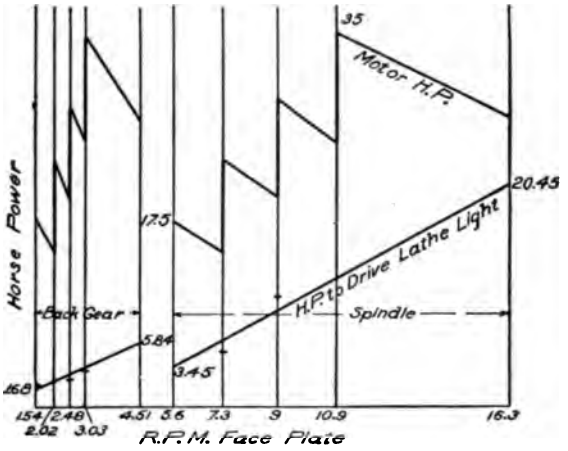


Fig. 13.

system, but, in reality, they do not complicate matters to any great extent nor add materially to the cost of a large installation.

While, as stated above, the average machine tool may be considered as requiring constant horse-power through its working range, in numerous instances, particularly when dealing with large machinery, we find that requirements call for an increased horse-power with an increased speed. For such cases the multiple-voltage system is most desirable as is clearly shown by the curves in Fig. 13.

This data relates to a large gun lathe, driven by multiple-voltage apparatus. The lower curves are drawn through points determined by actual test and show the power required to drive

the lathe with face plate in place, but otherwise running light. The power available for useful work is represented by the vertical height between the curves just referred to and the upper ones, which show the relation between horse-power and speed of a standard 35-horse power Crocker-Wheeler motor. Such examples are, of course, exceptional.

Thus far, I have assumed the use of the same range in motor speeds, when operating on the spindle, backgear, and triple gear, and in the case of field weakening motors, or those operating on a

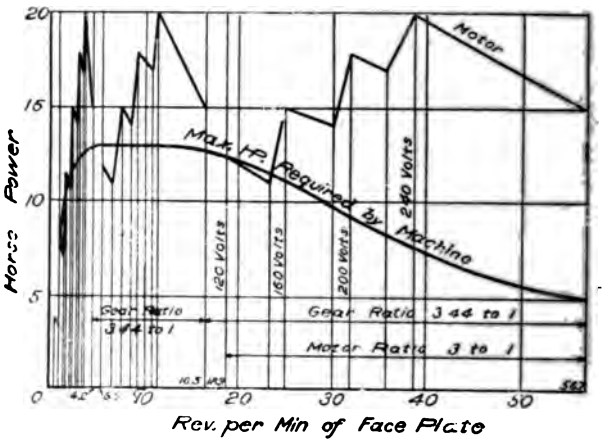
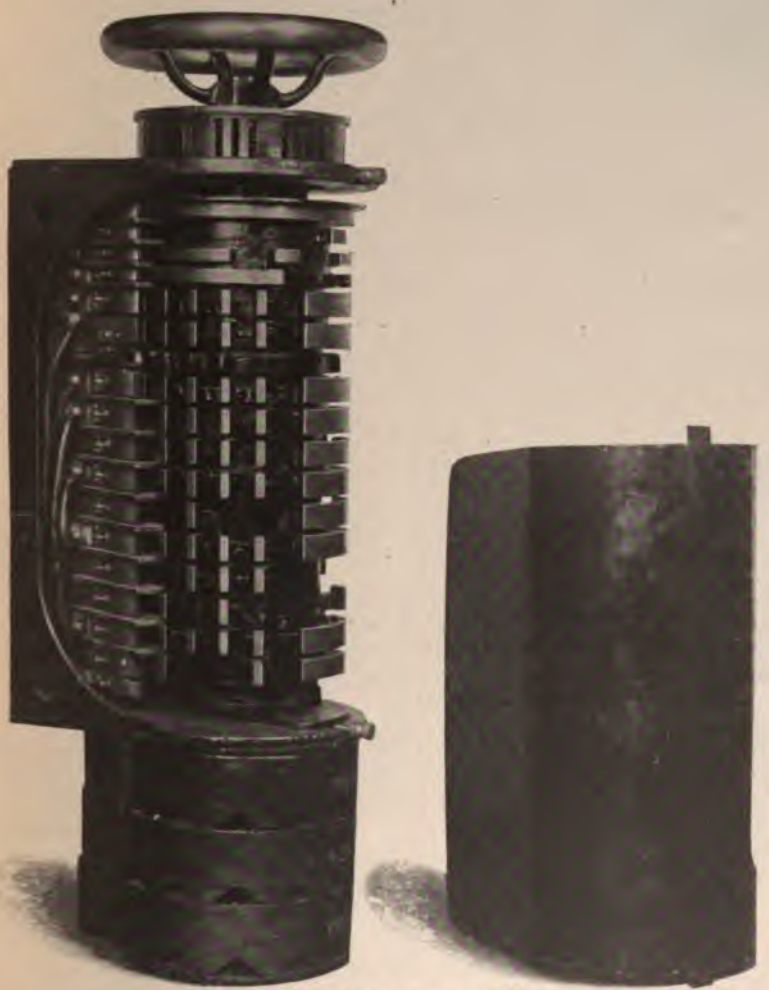


Fig. 14.

balanced three-wire system and rated as above there would not be any advantage in doing otherwise. The characteristics of the multiple-voltage system, however, are such that a smaller motor can frequently be used. The gear ratios are determined by the nature of the load curve. This fact was borne in mind when plotting the curves shown in Fig. 14 relative to multiple-voltage equipment for lathe A.-B. Company.

A motor weighing 2,350 lbs. and operating from 236 r.p.m. to 820 r.p.m. is recommended by one of the leading manufacturers of this apparatus. They prefer to rate their motors very conservatively, which accounts for the decrease in horse-power with field weakening. By actual test their motors stand up under these conditions as well as many other makes that are said to deliver constant horse-power through a range of 2 to 1.



MULTIPLE-VOLTAGE CONTROLLER.

Crocker-Wheeler Company.

(3) NOTES CONCERNING DIFFERENT MAKES OF APPARATUS.

In every instance final decision must rest with the perfection of apparatus. One of the most important details so far as efficient shop use of the motor drive is concerned is the controlling mechanism. For machine-shop duty thoroughly rugged and compact controllers are required. No contacts should be exposed as is now the case with the apparatus furnished by a number of manufacturers of field weakening motors. With thoroughly efficient apparatus it is practically impossible to damage either the motor or controller by the rapid operation of the latter. I do not mean by this that it is well to swing the controller handle suddenly from the off position to the full-speed point, but such action should not result in destructive sparking at the commutator or arcing at the controller points.

The satisfactory operation of a controller for the conditions under consideration depends largely upon the success with which the manufacturer has fulfilled the following conditions:

(1) Controllers should be completely inclosed in iron casing.

(2) It should be impossible through the manipulation of the controller to stop the motor at any place on the scale other than the off position.

(3) Rapid operation of the controller should not cause serious damage to either motor or controller.

(4) They should be so designed that they can be easily operated from a convenient point on machine.

(5) A sufficient number of speeds should be provided, depending on machine requirements.

(6) Controllers that require frequent operation must be designed with liberal contact surface and more rugged in every respect than those used principally as "speed setters," and as a result only operated at intervals.

(7) The design should permit of repairs with the greatest ease. In this connection the location and type of resistance grids should be given careful consideration.

(8) Each speed should be clearly defined either by a star-wheel and pawl or other means.

A number of manufacturers have placed on the market controllers that are giving good results, and in most respects comply with the above requirements.

Motors have been designed to accompany these controllers that are well suited for application to machines, in so far as their external dimensions are concerned, but at the same time we feel sure that the electrical manufacturers who are willing in certain cases to depart from present designs will gain a strong position with the machine builders.

(4) CONCLUSIONS.

In all probability a paper such as I have prepared for this meeting of electrical engineers, would have seemed decidedly out of place some years ago. I have dealt with matters which would then have been considered the business of the machine builder or mechanical engineer, and not requiring the thought and study of the electrical profession. It is now realized, however, that the motor-drive problem presents many new features, and is a distinctly different one from the manufacture and sale of standard generators, for example. The earning power of the latter is largely dependent upon the design and workmanship, features that can be passed upon before the machinery leaves the works. If a power plant is found to be too small, more units can be readily added without in any way interfering with those in use. On the other hand the earning power of a motor equipment for individual operation of machines depends largely on conditions over which the manufacturer has no control. The continued growth of this department of his plant, however, is governed by results actually obtained with his product under working conditions, so to protect himself he is called upon to see that the proper equipment is selected, and if possible, advise as to its use. As far as the customer is concerned, it would usually be better for him to close his eyes and grasp any one of possibly four makes of apparatus, devoting his time to its proper installation and operation, rather than reversing the process as is so often done.

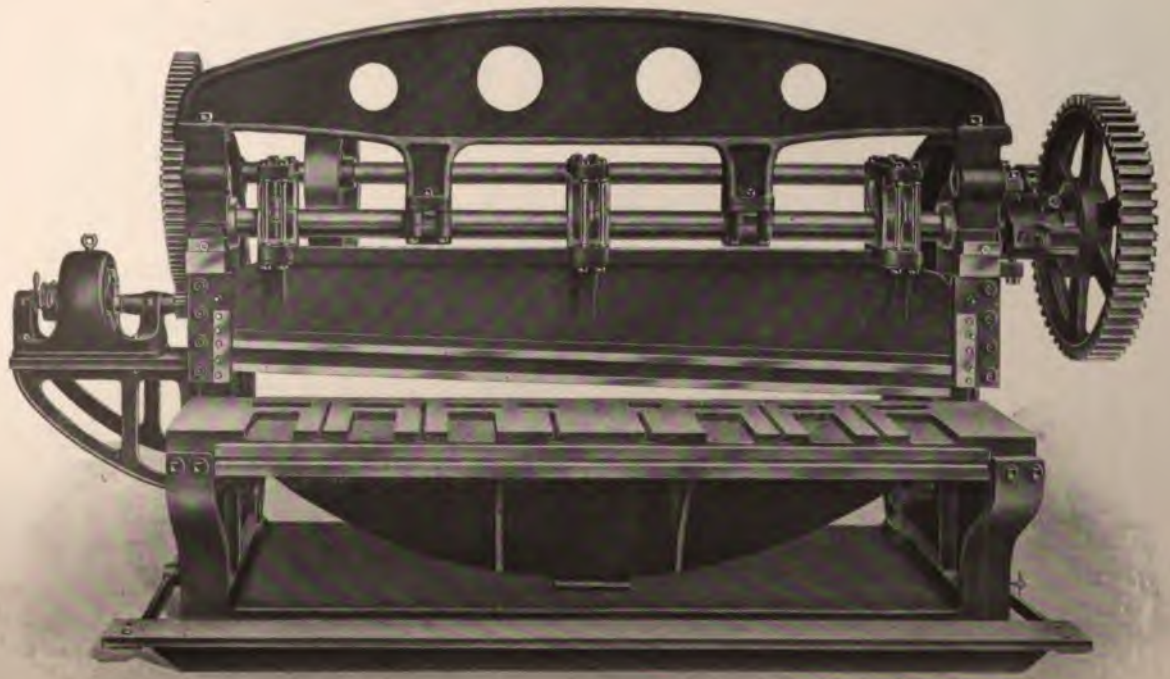
The conclusions reached above concerning the motors required for the 60-in. lathe are summarized in the table below:

	Weight.	Min. R.P.M.	Max. R.P.M.
Field weakening	2,300	225	787
Three-wire system	2,600	220	770
Four-wire system	2,350	235	820

It must be remembered that the ability of these motors to fill the imposed conditions was not determined by actual test, the data being the recommendations of well-known electrical companies who manufacture the respective types of apparatus. These figures should at least make it clear that many statements constantly made concerning the size of motor required for a given horse-power and speed range cannot be other than erroneous.

I pointed out above the conditions which must be met by the machine builder necessitating the selection of a type that does not require for its operation special auxiliary apparatus. While motors operating on two wires and giving a range as high as 4 to 1 by means of field weakening do not at present give as good all-round results as those operating on the multiple-voltage and three-wire systems, we feel that their adoption by the manufacturers referred to is certainly justified. When this is more fully appreciated the electrical companies should rapidly achieve better results in this direction.

The customer purchasing for his own use should, on the other hand, *differentiate clearly between the machine builders' requirements and his own*, for in many cases he can secure more satisfactory results, all things considered, through the adoption of a system combining with field weakening a number of voltages.



GUILLOTINE SHEARS. MOTOR DRIVEN.

Erie Foundry Company.

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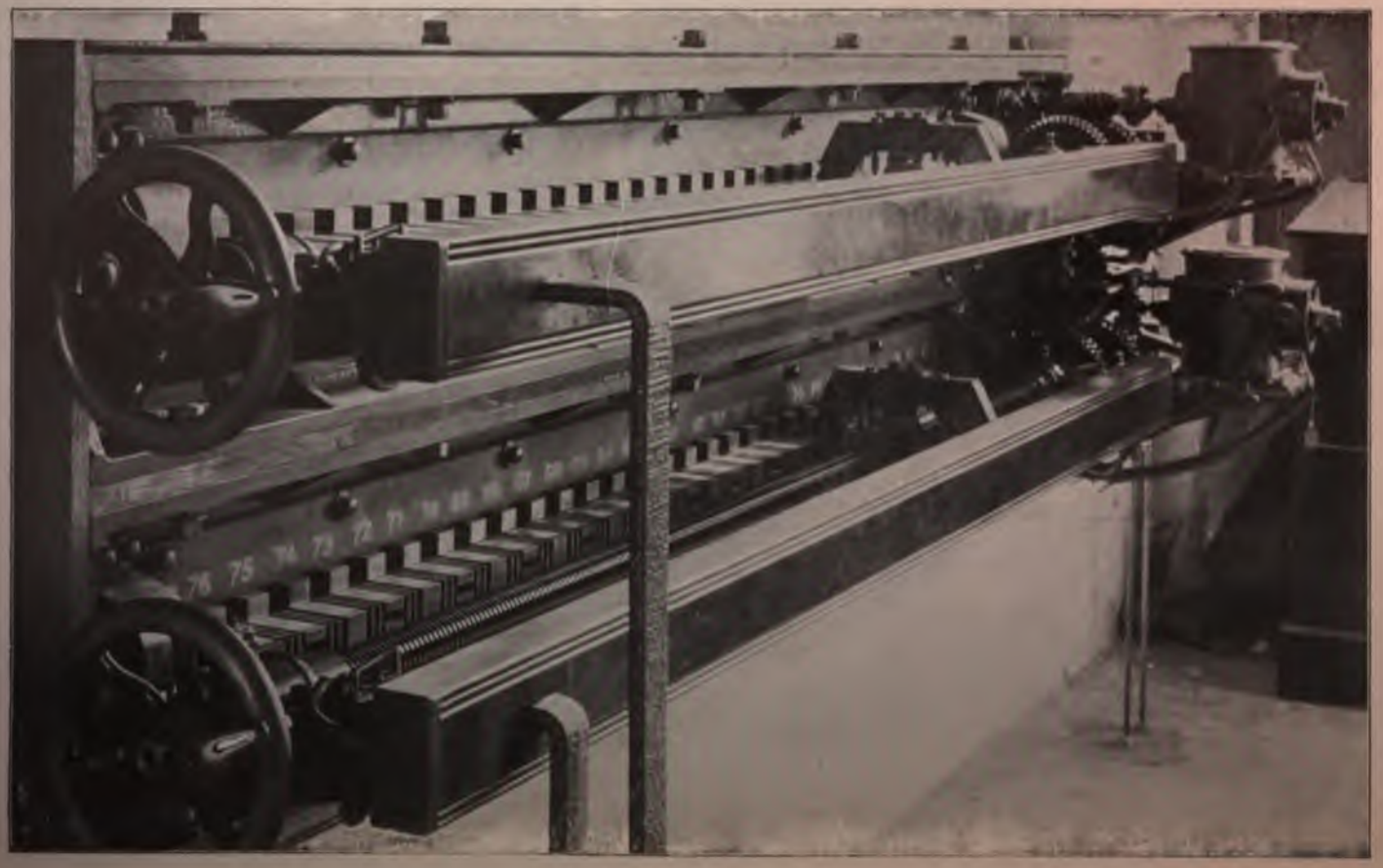


End Cell Regulating Switches

Minneapolis General Electric Company

STORAGE BATTERIES.

Storage or secondary batteries, also called accumulators, consist of cells in which a chemical change is brought about by passing an electric current through them, thereby rendering them capable of giving back electrical energy by discharging them until they return to their original chemical condition.

Ordinarily, a storage battery consists, essentially, of two sets of plates suspended in a chemical solution. The plates are of metal or metallic oxide, and the solution is incapable of acting upon them until an electric current is passed from one plate to the other. This current decomposes the electrolyte; one of its constituent elements or radicals goes to one plate, and the remaining constituent to the other, so that when the passage of the current ceases there are two chemical elements or radicals with a tendency to unite, and upon combination the energy evolved appears as an electric current, which flows in the opposite direction to the charging current. This flow of current continues until the cell is restored to its original condition; when this occurs the cell is said to be discharged.

A Primary Cell is one in which electrical energy is produced by the chemical action of one or two solutions on the plates of the cell. When the solutions or plates are exhausted, they are *not* restored to their original condition by the passage of an electrical current.

This reversibility or regeneration is the fundamental difference between storage and primary cells.

An Electrolyte is a chemical compound, capable of acting as an electrical conductor, and while so acting, undergoes chemical decomposition. This phenomenon is called electrolysis.

For example, when hydrochloric acid is decomposed by electrical energy, it is decomposed into the elementary gases hydrogen (H) and chlorine (Cl). The chemical formula for this action is,

$$2H\,Cl + \text{Electrical energy} = Cl_2 + H_2.$$

When sulphuric acid is electrolyzed, it is at first split up into hydrogen (H_2) and the radical sulphion (SO_4); the latter combines with the water of solution present and reforms sulphuric acid (H_2SO_4) and oxygen is liberated. The chemical equations for the above primary and secondary reactions are:

$$2H_2O + 2H_2SO_4 + \text{Electrical energy} = 2H_2 + 2SO_4 + 2H_2O$$
$$2H_2 + 2SO_4 + 2H_2O = 2H_2 + 2H_2SO_4 + O_2$$

The modern theory of electrolysis assumes that in an electrolytic solution there are always free ions which wander around promiscuously, until the application of an electric current directs their wanderings into certain definite directions.

Any salt dissolved in water is ionized, that is, some portion is separated into the two component parts of the salt.

When certain metals such as potassium or sodium are free in an ionized solution they are said to be in an allotropic state, and when the current is passed through the solution, the metal is freed from its allotropic state, and will in such cases, form hydrates, (KOH), (NaOH). The theory also states that the conductivity of electrolytes is due to the presence of these ions, and that the non-ionized portion does not conduct.

In 1802, soon after the invention of the primary cell by Volta, Gautherot demonstrated the fact that platinum wires, after being used to electrolize saline solutions, were able to produce secondary currents. Volta, Ritter, Davy and others noted similar effects, the phenomenon being what is commonly called polarization. In 1859 Planté undertook a series of experiments with the object of studying and magnifying this effect and finally developed the Planté type of storage battery; nearly all successful types of storage batteries of the present day are based upon Planté's invention.

Types of Storage Batteries:

Planté.
Faure.
Combination of Planté and Faure
Non-lead.

PLANTÉ BATTERY.

This cell was originally made by placing two plates of metallic lead in a vessel containing dilute sulphuric acid. These plates were connected to an electric generator, and a current sent through the cell, which decomposed the electrolyte and oxidized the positive plate. The cell was then discharged; but the energy obtained was very small, since the action was confined to the immediate surface of the plates. By repeated charging and discharging first in one direction and then in the other, the oxidation penetrated deeper and deeper into both plates, thus increasing the storage capacity of the cell.

The chief difficulty with the Planté battery was the great length of time required for "forming" the plates, which as just explained consists in converting the surface of the plates into active materials, by repeated chargings and dischargings. This takes a long time and is expensive, as it requires a large consumption of electrical energy. Later on in his investigations, Planté hastened this forming process by pickling the plates in dilute nitric acid, then washing them in a 10 per cent sulphuric acid solution, after which they were electrically formed. One difficulty with the Planté system was that plates well adapted to the forming process were difficult to make.

In 1881 Faure devised the method of pasting the lead oxide or active material directly upon the plates. This largely avoids the tedious forming process; but the plates thus produced are not as durable as the Planté elements, being more likely to disintegrate, because the paste is not an integral part of the plate and there is considerable difference in the coefficients of expansion of lead and of the oxide.

Innumerable forms of storage batteries have been invented, and many of them have been exploited, in which copper, zinc, iron and other metals or elements instead of lead were used; but almost all of those now being manufactured and used commercially are of some lead type. Such being the case, it is safe to assume or infer, that this lead combination possesses distinctive features not present in the other combinations; and upon investigation, it is apparent that these features are that the electrodes, the active materials and the compounds formed from them are,

under every normal condition of use, insoluble in the electrolyte employed.

In nearly every other form of battery now on the market, one or even both of the electrodes or materials formed on them are soluble in the electrolyte, and this solubility is detrimental to the storage power and life of the cell.

General Principles of the Storage Battery. Any primary battery will act as a storage battery provided its chemical action is reversible. The ordinary gravity cell, for example, may be regenerated by sending a current through it in the direction opposite to that produced by it. The zinc sulphate and the metallic copper are thus reconverted into metallic zinc and sulphate of copper respectively, the chemical action being

$$ZnSO_4 + Cu + \text{Electricity} = Zn + CuSO_4,$$

which is exactly the reverse of the action in the primary cell. There are, however, practical difficulties in the continued recharging of a spent gravity cell, due to the ultimate mixture of the sulphate solutions and the copper salt reaching the negative electrode, where it is deposited and sets up destructive local action.

In some forms of primary cells, the chemical action liberates a gas that escapes, so that the action is obviously irreversible.

Chemical Action in Lead Storage Batteries. The exact nature of the chemical changes which occur in lead batteries, is not yet fully established. Planté believed the charging action to consist in the formation of peroxide of lead (PbO_2) on the positive plate, and metallic lead on the negative, which were converted into lead oxide (PbO) on both plates by the discharge. Some authorities still maintain this to be the chief reaction; but it has been shown by Gladston and Tribe, and corroborated by subsequent investigations, that the formation of lead sulphate plays an important part.

The probable reaction may be represented as follows:

	Positive Plate.		Electrolyte.		Negative Plate.
Charged Condition	PbO_2	+	$2H_2SO_4$	+	Pb
Discharged "	$PbSO_4$	+	$2H_2O$	+	$PbSO_4$
Charging Current			⟩⟩⟩——⟩		
Discharging Current			⟨——⟨⟨⟨		

According to the above equations, the active material on both plates is converted into lead sulphate when the battery is discharged. The reasons for believing this to occur are: *first*, chemical analysis shows that lead sulphate exists in the discharged plate, *second*, the density of the electrolyte decreases during the discharge of the cell, corresponding to the consumption of sulphuric acid and the formation of water as shown in the above reactions, *third*, on the thermo-chemical grounds, the combination of lead and oxygen as lead oxide (PbO) does not evolve sufficient energy to account for the E. M. F. or voltage produced.

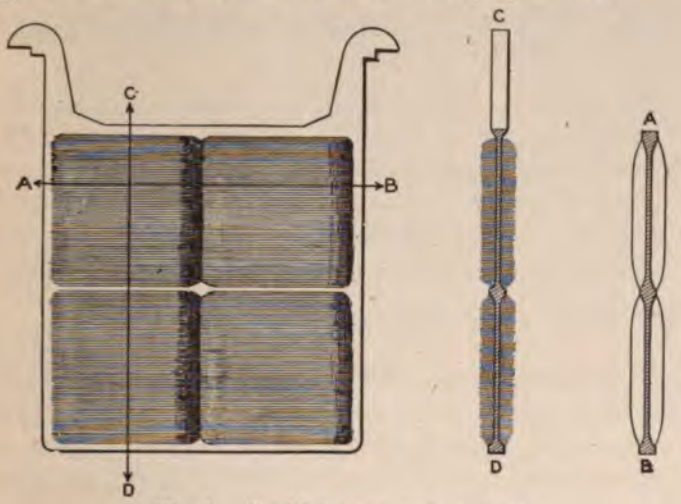


Fig. 1. Gould Storage Battery Plate.

Storage Batteries of the Planté Type. It was noted that the serious objection to the Planté battery was the great length of time necessary to form the plates, and how Planté treated them with nitric acid to hasten this action. Other methods are used to obtain a quickened formation, and are tabulated as follows:

1. *Mechanical Action:* Laminated plates, made up of lead ribbons. The surface of the plate is grooved with some forming tool. Built up of lead wires, etc.
2. *Chemical:* Treating the plates in some pickling bath, to produce initial oxidation.
3. *Electrolytic:* Forming a plate of some compound of lead or an alloy, and either reducing the compound or eating the foreign matter away, leaving a porous lead plate.

The Gould Storage Battery. This battery is made by the Gould Electric Storage Battery Company of N. Y., and the plates are produced by a combination of the first and second methods. The plates or blanks are placed in steel frames and given a reciprocating motion between two revolving shafts which carry grooving discs, giving the plates a surface as shown in Fig. 1. No lead is removed by this process but the surface is ploughed up. It is then subjected to electro-chemical treatment to form the active material. The completed cells range in size from a cell of three plates 3 inches by 3 inches, to one of one hundred and five plates each 15.5 inches by 31 inches, and in capacity in ampere-hours from five to seventeen thousand.

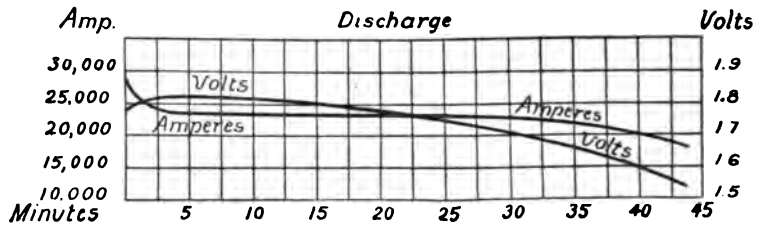


Fig. 2. Discharge Curve of a Gould Type "T" Battery.

The curves shown in Fig. 2 are reproductions of curves obtained from tests of one of their type — T batteries, plates each 15.5 inches by 31 inches, and 101 in number, made at the Pan American Exposition. The weight of this battery complete is about seven thousand and fifty pounds.

The Crompton-Howell Battery. A standard form successfully used in England, is of the Planté type, the plates being composed of a porous crystalline lead, made according to method 3 (see page 5) and afterwards "formed" by repeated charges and discharges. The regular dimensions of the plates are 9 inches by 9 inches by ¼ inch, and the different sizes of cell are made up by varying the number of plates. A cell of this type with sixty-one plates can maintain a discharge of 1000 amperes for thirty minutes without a serious fall in potential.

FAURE TYPES OF STORAGE BATTERY.

As has been stated, the difficulty with the Faure type is the natural tendency it has to disintegrate. Various methods to

increase the permanency of the adhesion of the active material have been suggested of which the most important are as follows:

1. Plates are grooved, roughened or pocketed.

2. Plates are entirely perforated, the holes being circular, or rectangular, and varying in cross section: some have a uniform section through the grid A, Fig. 3, others are contracted at the

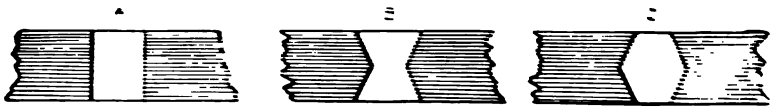


Fig. 3. Different Cross Sections of Faure Plate Perforations.

center B and again they may be expanded at the center of the grid C.

3. The active materials may be enclosed in either a conducting or non-conducting cage.

4. The plates may be made up entirely of active material.

Faure cells usually have a greater weight efficiency than Planté types because the proportion of active material may be made greater.

The E. P. S. Battery is one of the most important of the

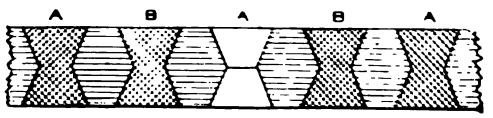


Fig. 4. Section of E. P. S. Battery Plate.

Faure type, its name being the initials of the Electric Power Storage Company by which it is manufactured in England. It is sometimes called the Faure-Sellon-Volckmar cell, being made under the combined patents of these and several other inventors.

The plates consist of lead grids cast in an iron mold, and have the cross-section shown in Fig. 4. The later types have a thin perforated strip of metal (lead) running across each opening midway between the edges. The holes A in the grid are completely filled with a paste of red lead or minium (Pb_3O_4) and dilute sulphuric acid for the positive, while the paste for the negative

consists of minium, or litharge (PbO) and dilute sulphuric acid or a magnesium sulphate solution. These pastes are pressed into the grids and dried.

The plates are hardened in dilute sulphuric acid, after which they are ready for forming. A strong current of 48 hours' duration is required for the positive plate and twenty-four hours is required for the formation of the negative plate. To prevent short circuiting after the cells are set up, the plates have glass rod separators placed between them.

The E. P. S. batteries are made in many different sizes and types, of which the L type is a good example, being used extensively in isolated plants. Data of this type are as follows:

E. P. S. ACCUMULATOR, L. TYPE.

No. of Plates.	Maximum Normal Charge or Discharge Rate.	Capacity Ampere Hours.	Approximate External Dimensions.			Weight Complete with Acid Wooden Cell.
			Length.	Width.	Height.	
7	13 amperes	130	5¼ in.	13¼ in. for wooden and 12 for glass cell.	18 in. for wooden and 13¼ for glass cell.	74 lbs.
11	22 "	220	8			107 "
15	30 "	330	9½			143 "
23	46 "	500	14½			228 "
31	60 "	660	19			286 "

One of the smaller types of the E. P. S. battery is used extensively in England in electric vehicle work.

The Exide Battery is manufactured by the Electric Storage Battery Co., of Philadelphia, chiefly for electric vehicle duty. The plates are of the Faure type, and consist of lead-antimony grids (about 5 per cent antimony) pasted with oxides of lead.

The grid for the positive plate is of the cage type, consisting of thin vertical ribs, the edges of which are flush with the faces of the plate, and connected by small bars of a triangular cross section; the bars on one face are staggered with respect to those on the other side. This finished form is then pasted up with red lead (Pb_3O_4) and formed in the usual way; the thickness of the

finished plate is about $\frac{7}{32}$ inch. From this description it is evident that the plate is made up in accordance with method 3 described on page 7, the enclosing cage being of conducting material. The active material is in the form of rectangular pencils extending from the top of the plate to the bottom. The thin flat ribs are on two sides of these pencils and the triangular cross pieces are imbedded in the other two sides which constitute the faces of the plates. The Exide cell is shown in Fig. 5.

Fig. 5. Exide Battery.

The negative plate consists of a thin antimony lead sheet enclosed by a light frame of cast lead. The body of the sheet is perforated at regular points and very close together. These perforations are not actual punchings (being made by a tool which does not remove the material) but are simply holes torn in the plate leaving the material around the hole in ragged projections which curve back towards the sheet, and form as it were a series of hooks. These projections are formed on both sides of the plates.

The grid is then pasted with litharge (PbO) on both faces; it is held to the plate by the "hooks" as well as being "riveted"

by passing through the holes which the projections surround. The thickness of this finished plate is about $\frac{3}{16}$ inch.

When assembled, the plates are placed in rubber jars of

DATA SHEET EXIDE CELLS. *

TYPE.	—M. V.—								—P. V.—				
Number of Plates.	7	9	11	13	15	17	19	5	7	9	11
Discharge in Amps for 4 Hours.	21	28	35	42	49	56	63	12	18	24	30
Size of Plates.											
Length (inches).	5¾	same	same	same	same	same	same	4 1/8	same	same	same
Height (inches).	8¾	same	same	same	same	same	same	8¾	same	same	same
Outside Measures of Rubber Jars.											
Width (inches).	2 7/8	3¼	4¼	4 1/8	5 3/8	6¼	7 3/8	1 1/8	2 5/8	3¼	4¼
Length (inches).	6 1/8	same	same	same	same	same	same	5 7/8	same	same	same
Height (inches).	11¼	same	same	same	same	same	same	11¼	same	same	same
Weight in Pounds.											
Elements.	15¾	20¾	25¼	30¼	35	40	44¾	9¼	13¼	17¼	21¼
Electrolyte.	2¼	3¼	4¼	6¼	7	8	8¾	1¼	2¼	3	4¼
Complete Cell.	19¼	25¾	31¼	38¾	44¼	50	56	11¼	17¼	21¾	27¼

* Note: For data on the "Express Type" of exide cell see literature of the Electric Storage Battery Company, Philadelphia.

dimensions as above, and separated from each other by wooden partitions. In addition a perforated rubber sheet is placed against the faces of the positive plates.

The brougham or hansom battery of this type of cell consists of 44 cells of TV-9 size, having four positive and five negative plates. The weight of this outfit complete with tray is about

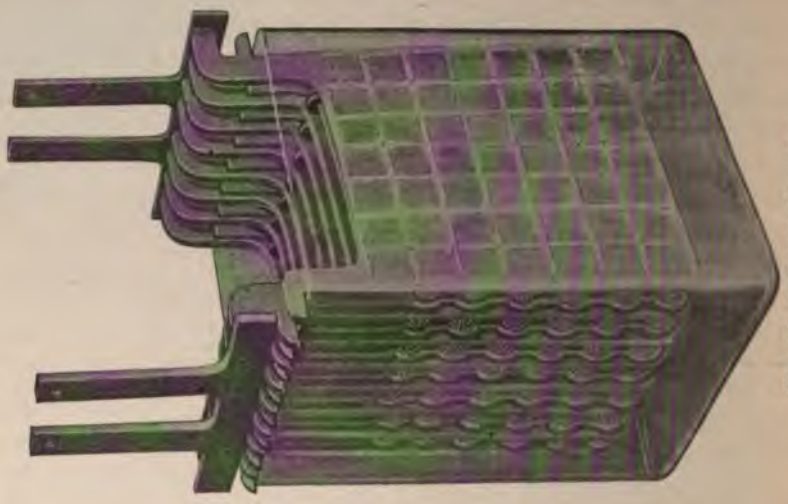
1659 pounds, the capacity 156 ampere hours (4 hour, 39 ampere rate), the average voltage during discharge about 1.98 volts per cell or 87 volts for 44 in series, the total watt-hour output being therefore 13,572 or 8.18 per pound of battery complete including trays.

COMBINATIONS OF PLANTE AND FAURE TYPES.

The Chloride Battery, in the form which was manufactured until recently by the Electric Storage Battery Company and allied companies in England, France and Germany, is a compromise between the Planté and Faure types, the positive being a Planté type and the negative of practically the Faure type.

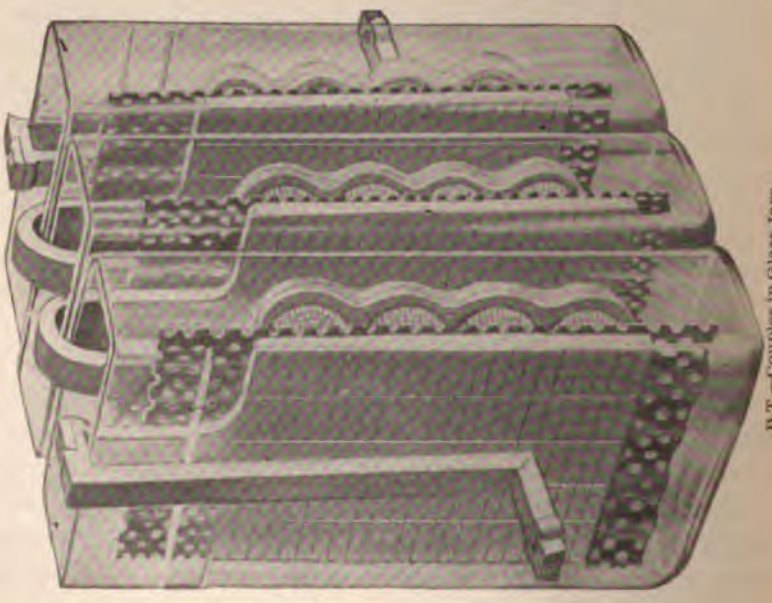
The principal features in the manufacture of this battery are as follows: The first step is the production of finely divided lead, which is made by directing a blast of air against a stream of the molten metal, producing a spray of lead which upon cooling falls as a powder. This powder is dissolved in nitric acid (HNO_3) and precipitated as lead chloride ($PbCl_2$) on the addition of hydrochloric acid (HCl). This chloride washed and dried forms the basis of the material which afterwards becomes active in the negative plate B, Fig. 6. The lead chloride is mixed with zinc chloride, and melted in crucibles, then cast into small pastiles or tablets about $\frac{3}{4}$ inch square and of the thickness of the negative plate, which according to the size of the battery varies from $\frac{1}{4}$ inch to $\frac{5}{16}$ inch. These tablets are then put in molds and held in place by pins, so that they clear each other by .2 inch and are at the same distance from the edges of the mold. Molten lead is then forced into the mold under about seventy-five pounds pressure, completely filling the space between the tablets. The result is a solid lead grid holding small squares of active material. The lead chloride is then reduced by stacking the plates in a tank containing a dilute solution of zinc chloride, slabs of zinc being alternated with them. This assemblage of plates constitutes a short-circuited cell, the lead chloride being reduced to metallic lead. The plates are then thoroughly washed to remove all traces of zinc chloride.

In the new form of negative plate which has replaced the chloride type just discussed, the negative consists of a "pocketed" grid, the opening being filled with a litharge paste; it is then covered with perforated lead sheets which are cast integral with



Type F—15 Plates in Glass Jar.

Fig. 6.



B T.—Couples in Glass Jars.

the grid. The positive plate is a firm grid, composed of lead alloyed with about 5 per cent of antimony, about $\frac{7}{16}$ of an inch thick, with circular holes $\frac{25}{32}$ of an inch in diameter, staggered so that the nearest points are .2 of an inch apart. Corrugated lead ribbons $\frac{7}{16}$ of an inch wide are then rolled up into close spirals $\frac{25}{32}$ of an inch in diameter, which are forced into the circular holes of the plate.

By electro-chemical action, these spirals are formed into active material, the process requiring about thirty hours ; at the same time the spirals expand so that they tend to fit still more

DATA CHLORIDE BATTERY.

TYPES.	B.	C.		BT.	CT.	PT.	D.		E.		F.	G.		H.	
Size of Plate, inches	3x3	4½x4		3x4	5x5	8½x5	6x6		7¾x7¾		11x10½	15½x15½		15½x31	
Number of plates	3	3	7	2	2	2	3	13	5	15	9	27	11	75	21	75
Disch. in Amperes — For 8 hrs.	⅜	1½	3½	¾	1½	3	2½	15	10	35	40	130	100	740	400	1480
Disch. in Amperes — 5	¾	1¾	5¼	1	2	4½	3½	21	14	49	56	182	140	1036	560	2072
Disch. in Amperes — 3	1¼	2½	7½	1½	3	6	5	30	20	70	80	260	200	1480	800	2960
Disch. in Amperes — 1							10	60	40	140	160	520	400	2960	1600	5920
Normal Charge Rate	⅜	1½	3½	¾	1½	3	2½	15	10	35	40	130	100	740	400	1480
Outside dim. of glass jars, inches — Width	2½	3½	5¼	1¾	2¼	2½	3¼	11	5½	11	9	No glass jars for these large sizes.				
Outside dim. of glass jars, inches — Length	4	5¼	5¼	3¾	6¼	6	7⅞	8¼	9⅛	9⅛	12⅝					
Outside dim. of glass jars, inches — Height	6½	7¼	7¼	6¾	8	12	9½	9¼	11⅜	11⅜	17					
Outside dim. for lead-lined wooden tanks — Width											13¾	28½	15½	69⅛	25½	69⅝
Outside dim. for lead-lined wooden tanks — Length											15	15	19¾	21¼	21¼	21¼
Outside dim. for lead-lined wooden tanks — Height											20¼	20¼	26	27⅞	48¾	49¾
Wht. of cell complete (lbs.)	5½	10½	19	3½	7½	13½	19½	64	48¾	112	175					
Ditto. Lead-lined tanks.											250	615	561	3260	1885	5986

closely in the grids. This form of positive is that known as the Manchester Plate.

Modern types of chloride accumulator are shown in Fig. 6.

In setting up the cells, the plates are separated from each other by special wood partitions, having vertical grooves to facilitate the rising of the gases. Sometimes glass rods are used as separators.

The table gives the data of the various types and sizes of cells. To save space only the smallest and largest sizes of each type are given, but in all cases intermediate sizes are made with

every odd number of plates. The capacities, weights, etc., are of course nearly proportional to the number of plates.

The smaller sizes are provided with either rubber or glass jars, and the larger ones, from F up, with lead-lined tanks.

The Tudor Cell has been very extensively used in Europe, and to some extent in this country, although it is no longer manufactured here. The American patent rights are controlled by the Electric Storage Battery Company.

The plates consist of rolled, grooved sheets as shown in Fig. 7, A being the hollows or grooves into which the paste is set and B the lead frame. The thickness of the plate between opposite grooves is about .12 inch for the positive, and about .06 inch for the negative. The width of grooves on the positive plate is also about .12 inch, while on the negative it is about .08 inch. The grooves are first coated with a thin layer of peroxide of lead (PbO_2) by electrolysis, and then packed with the oxides as required; the plates are then rolled to "fix" the paste. This treatment of the grid with an electrolytic bath before applying the active material, is covered by U. S. patent No. 413,112.

TUDOR CELLS.

Type.	Available Capacity.	Maximum Current in Amperes.		Dimensions of Cells in Centimeters.			Total Weight.
	Amp. Hours.	Charge.	Discharge.	Length.	Width.	Height.	Kgms.
I	26	6	8	12	21	35	10
V	91	21	28	30	21	35	30
X	270	54	72	42	42	55	110
XIV	630	126	168	74	42	55	230

In addition to those given above, all of the intermediate sizes are made.

A battery of larger cells is in use in the Head Place Station of the Edison Company of Boston, Mass., a description of which is given in the Electrical Engineer (N. Y.) of Sept. 18, 1895. The plant contains two batteries of 72 cells each. Each cell consists of a lead-lined wooden box, 3 feet 10 inches long, 3 feet 4 inches wide, and 3 feet deep, in which are suspended 18 positive

and 19 negative frames. Each positive frame is composed of 16 plates 7 inches square ; while each negative frame has 4 plates 14 inches square, thus giving an enormous surface in each cell. The plates are secured in their respective frames by lead strips. The frames are held in position about $\frac{1}{2}$ inch apart by vertical glass tubes, and rest upon thick glass plates placed on edge in the bottom of the cell; the frames being thus raised 6 inches above the floor of the cell. It is said that these two batteries combined are capable of supplying 6,600 amperes at 110 volts for $1\frac{1}{4}$ hours, which would usually cover the period of very heavy load. This is an output of 726 kilowatts, or nearly 1,000 horse-power for $1\frac{1}{4}$ hours, being a remarkably high discharge rate.

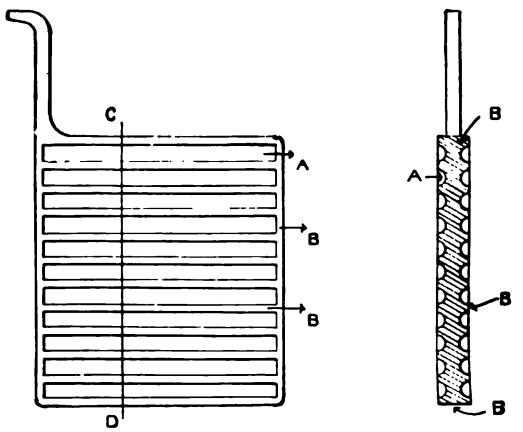


Fig. 7. The Tudor Battery Plate.

Formerly it was used in central stations, particularly where the rate of discharge was great, as for example when the total time of discharge was only $1\frac{1}{2}$ to 4 hours. For this work the negative plates were of the chloride type, the positives being the heavy Tudor plates described above.

Lithanode. Mr. Desmond Fitzgerald has made storage batteries with a positive plate consisting entirely of active materials made up of litharge (PbO) mixed with ammonium sulphate $(NH_4)_2\ SO_4$ which he pressed into the required shapes. This plate is converted into peroxide by chemical treatment. The negative of this cell consists of the ordinary lead plate. While this cell has an exceedingly high weight efficiency it is not of

much commercial importance, though used considerably in laboratory work.

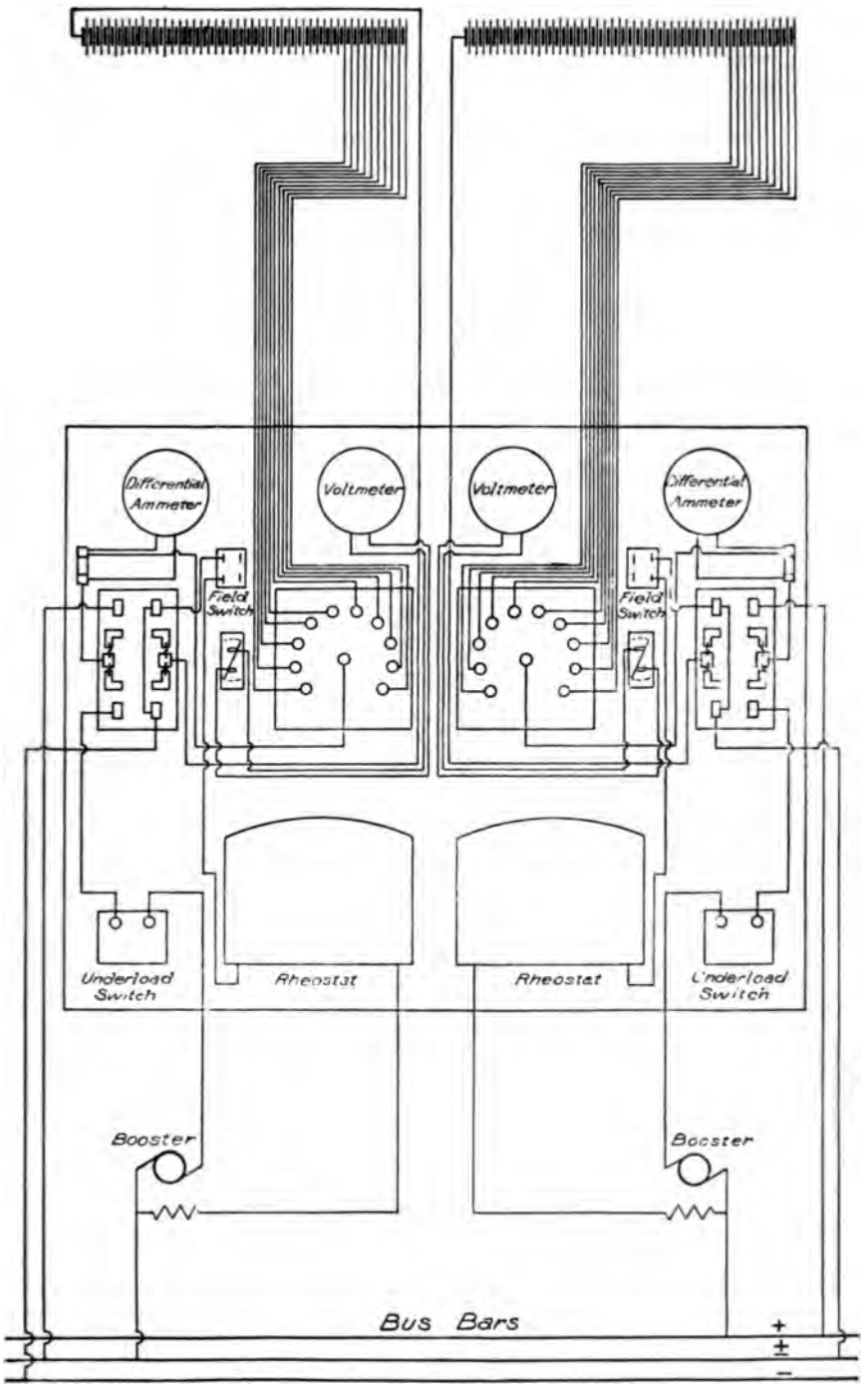
It is the tendency in Europe to make the positive plate of the Planté form and the negative of the Faure or pasted type. The reason for this is that while the Planté form makes an excellent positive, the pasted plate is better for a negative.

The practice in lead batteries is to make the negative plate of greater capacity than the positive, as the charging and discharging of a cell in service tends to produce or form more active material on the positive plate, whereas the negative plate is made to decrease, so that allowance for this is made as above stated.

Storage Batteries Containing Metals other than Lead. It has already been stated that almost any primary cell will act more or less perfectly as a secondary cell; as, for example, the common gravity battery. A great many have been devised in which the lead in one or both of the plates has been replaced by some other metal. For example, Reynier made the negative plate of zinc instead of lead, this zinc in discharging being converted into zinc sulphate, which dissolved in the electrolyte. The substitution of zinc for lead secures an increase in initial E. M. F. from 2.2 to 2.5 volts, and also allows of a considerable reduction in weight; since for the storage of a given amount of energy the weight of the zinc required is much less than that of the equivalent lead. A difficulty with this type of cell is the formation of "trees" of zinc on the negative plate during the charging process, which are likely to fall off or extend across to the positive plate, thus short-circuiting the cell.

Another difficulty is the difference in density of the solution between the top and bottom of the plates, the tendency being to exhaust the zinc sulphate from the upper portion of the liquid during charging. In order to avoid this trouble the plates have been arranged horizontally, so that the density would be uniform for each plate; but the difficulty then arises that the gases which form to a certain extent in almost all batteries collect between the plates and interfere with the chemical action and the passage of the current.

A similar type of cell has been manufactured by the Union Electric Company of New York, in which the negative plates con-



Switchboard Connections for Storage Battery Auxiliary

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sist of thin sheet copper covered with an amalgam of zinc, and the positive plates are made up of laminæ of lead held together by leaden rivets and perforated with numerous small holes, these positives being formed by the Planté process.

Waddell-Entz Accumulator. The copper-alkali-zinc primary battery of Lalande, Chaperon and Edison being reversible in action, can be used as a storage battery. Waddell and Entz have constructed accumulators on this principle. When discharged, the positive plate consists of porous copper; on charging the electrolyte is decomposed, metallic zinc being deposited on the negative plate. the porous copper of the positive plate is oxidized, and the liquid

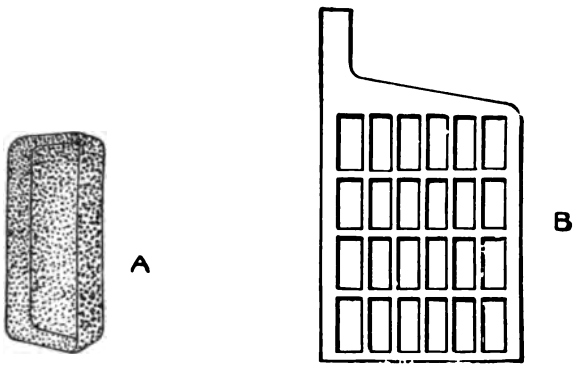


Fig. 8. Construction of Edison Battery Plate.

becomes converted into a solution of caustic potash (potassium hydrate).

This storage battery has been used with considerable success for traction purposes, but its E. M. F. is so low, being only about .7 volt, that it would require 170-180 cells for the ordinary 119 volt electric-lighting circuit, allowing for loss of potential in the battery and conductors. This number is three times as great as is required with the lead battery. This is a serious objection in this or any other low voltage cell.

The Edison Storage Battery manufactured by the Edison Storage Battery Company of Newark, N. J., consists of a positive plate of super-oxide of nickel (NiO_2) and a negative plate of iron, suspended in about a 20 per cent solution of caustic potash (KOH)

The mechanical construction of both plates (positive and negative) is the same, and the grids are made of nickel-plated steel, shaped as represented at B, Fig. 8. Each opening in the grid is filled with a perforated shallow pocket A or box of nickel-plated steel which contains the active material, and projects out beyond the body of the grid.

The active material is made up in the form of briquettes; one briquette being placed in each pocket. A perforated cover of nickel steel is placed over each pocket. After the plates are fully assembled they are subjected to a pressure of about 100 tons,

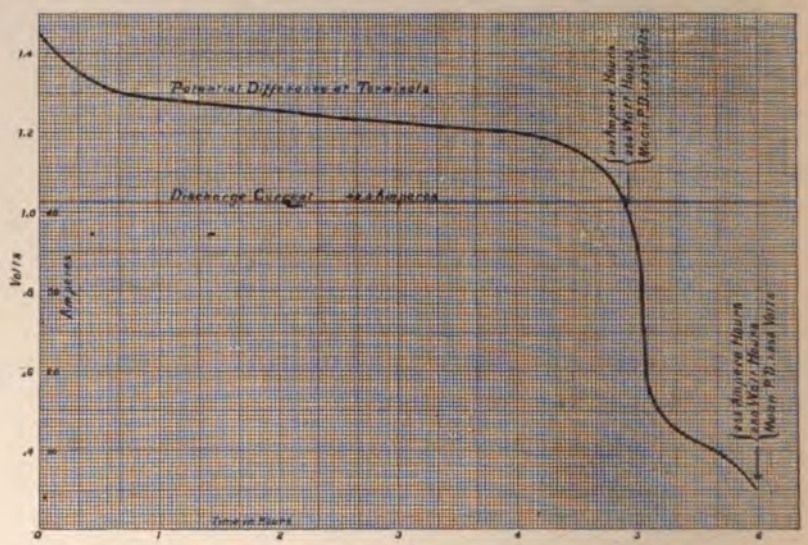


Fig. 9. Curve of Voltage of Edison Cell During Discharge.

which firmly forces all parts into a practically solid mass, making good electrical contact between the pockets and the grid, at the same time turning the edges of the pockets over their respective covers. The active material or briquette consists of a finely divided compound of nickel mixed with about an equal amount of flaked graphite, for the positive plate, and for the negative plate it consists of a finely divided compound of iron, with an equal amount of flaked graphite. This graphite has no chemical connection with the action of the cell but is used simply to increase the conductivity of the briquettes.

The finished plates have a thickness of about $\frac{1}{16}$ inch across the web, and across the pockets of about $\frac{1}{16}$ inch.

The size of the plate varies with the capacity of the cell, having a greater or less number of pockets. The containing jar is also made up of nickel-plated steel sheets.

The initial voltage of discharge after recent charge is 1.5 volts.

The mean voltage of full discharge is 1.1 volts.

This cell has an energy capacity or weight efficiency of 14 watt-hours per pound of complete cell.

Charging and discharging rates are alike, that is to say, the cell may be charged at a normal rate in $3\frac{1}{2}$ hours; or it may be charged at a high rate in one hour, without apparent detriment beyond lowering the efficiency.

The current enters the cell at the positive plate and oxidizes the nickel compound to the peroxide state, and reduces the iron compound in the negative plate to spongy iron.

The electrolyte in this cell simply acts as a path for the passage of the oxidizing and reducing ions, and its own chemical composition does not change

The cell is not appreciably influenced by changes in temperature. It is claimed that it may be fully discharged to the zero point of E. M. F. without injury, can be charged in reverse direction, then recharged to its original condition and suffer no loss in its storage capacity. The curve given in Fig. 9 shows a six hour discharge of an experimental cell, at a constant current of 42.5 amperes.

MANAGEMENT OF STORAGE BATTERIES.

In describing the handling of storage batteries, the various types of lead cells will be considered, as they constitute a very large majority of cells in commercial use.

The Battery Room. In the installation of a battery, the first point to be considered is its location. The room for this purpose should be dry, well ventilated and of a moderate temperature, otherwise not only will the evaporation of the electrolyte be excessive, but if the temperature be very high, the plates themselves will be affected and their life shortened. The floor walls and ceiling must be of some acid proof material, brick or tile being preferable, and the floor so made as to drain readily; an outlet being provided for the drainage system. If the room

should be an old one, and have a wooden floor, the floor should be coated with asphaltum paint, and lead trays placed below the batteries; any wood work or iron work in the room should be likewise treated.

The room should be sealed from the rest of the building, and located near the generating machinery and distribution switchboard, so that the copper cables may be low in cost. The windows in the battery room should be either of ground or painted glass, so that no direct rays of the sun may strike the cells, as the heat may crack the cells (glass) or increase the activity of the acid, which is not desirable.

In case the battery installation is in a cold climate, some device for keeping the electrolyte at a moderate temperature must be used. A simple plan is to suspend an incandescent lamp in the

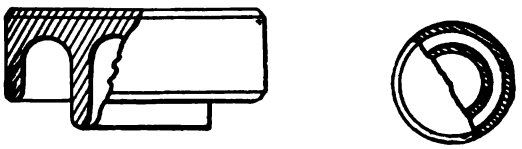


Fig. 10. Glass Insulator for Battery Support.

cell and have it connected to some automatic device which will put it out when the electrolyte is at the desired temperature or light it when the electrolyte is too cold.

Setting up the Cells. The battery is usually placed on the floor, or upon strong wooden shelves; Fig. 11 shows a form adapted to cells of medium size. Iron stands are sometimes used for large and heavy cells, but they must be protected from acid fumes and drip by several coats of an acid-proof paint. Wooden stands should be varnished, painted or soaked in paraffin for the same reason. It is important to have every cell accessible for inspection, cleaning and removal, it being desirable to reach both sides of the cell. There should also be sufficient head room between shelves so that the elements may be lifted out.

It is highly important that the cells be thoroughly insulated from each other, to avoid leakage of current. This is accomplished by standing each cell on four insulators of porcelain or glass of the design shown in Fig. 10. Porcelain is preferable to

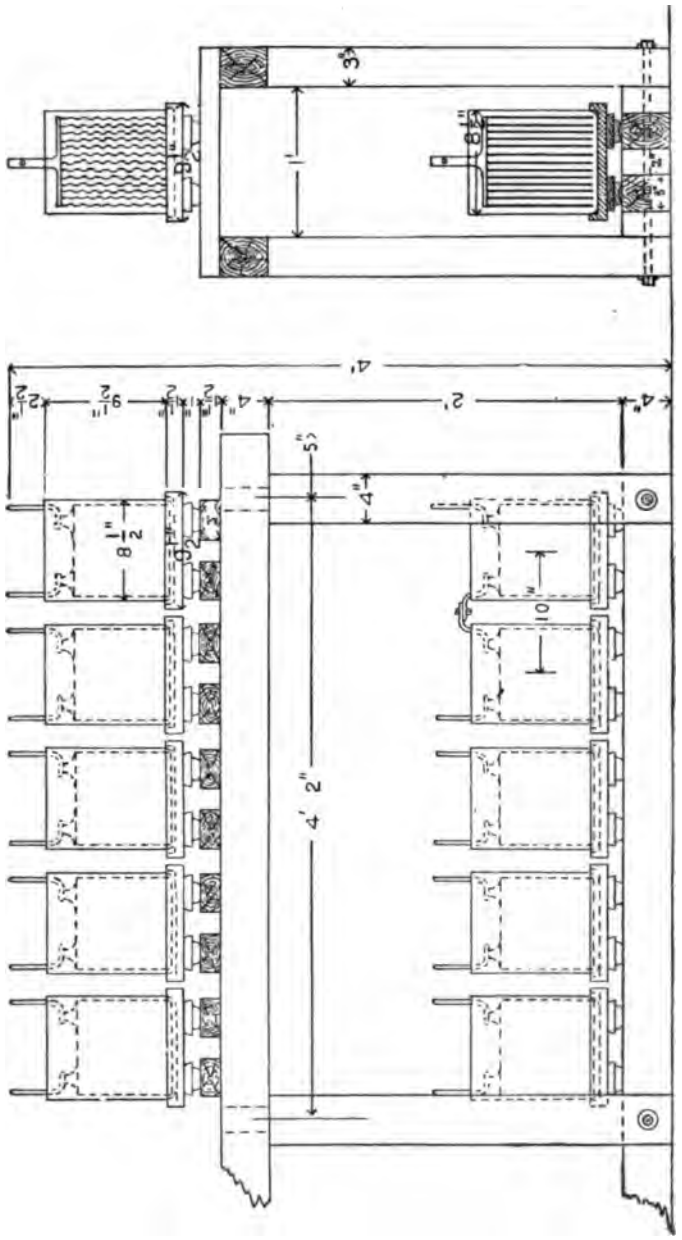


Fig. 11. Shelf Construction for Battery Support.

glass as the latter is sometimes pitted by the action of acid fumes.

Lead-lined tanks are usually set as follows: The floor is covered with a layer of glazed tile or brick; on this are placed two wooden stringers about 3 x 4 inches carefully painted with asphaltum varnish or some acid-proof paint. On these are set four insulators held in place by wooden pegs which are kept in position by pouring melted sulphur around them. On top of these are placed the battery tray and battery as indicated in Fig. 11.

Oil insulators were at first used, but oil collects and holds dust, and as dust is likely to cause leakage they are no longer used.

For very large lead tank outfits a double system of the supporting construction shown in Fig. 11 is used, but with individual stringers for each cell.

Glass cells are often set on wooden trays, which are filled with sand to distribute the strains and absorb the drip. Saw-dust was also used, but it becomes carbonized by the acid drip, and as this is likely to cause leakage, it has been abandoned.

In connecting the cells, which are usually put in series, great care should be taken to join the positive terminal of one cell to the negative of the next and so on. The color of the plate is the best indication of its polarity, the positive plate being a light brown when discharged and a chocolate color when charged, while the negative varies from a dark slate to a light slate color.

It may be noted at this point that the nomenclature, concerning storage batteries, is different from that of primary cells. The positive plate in the former is the peroxide plate (brown) and is that one from which the current flows out in discharging, whereas that would be the negative plate of a primary battery.

The positive pole or terminal in a storage battery is an extension of the positive plate, and is connected to the positive terminal of the dynamo in charging; consequently there is much less cause for confusion of terms than there is in the primary cell.

It is well to test the polarity of each cell and of the circuit before making connections. This may be done with any form of pole tester, or by the positive expedient of dipping the two terminals in dilute sulphuric acid, the one from which the most bubbles arise being negative. The connections should be scraped clean and

screwed up very tight, being also coated with acid-proof paint to avoid corrosion. The most satisfactory way to connect up a cell is to weld or "burn" the positive terminal to the negative terminal of the next cell, though soldered connections are good.

This soldering is done as follows: Two strips of lead and the terminals to be connected are very carefully cleansed; the lead strips are then clamped to the terminals, a mold placed around the joints and molten lead poured into it.

The Electrolyte. Practice varies considerably as to the strength of solution to use. Chemically pure sulphuric acid is poured into water until its density becomes about 1.2, and then the mixture is allowed to cool before pouring it into the cells. The electrolyte should completely cover the plates. Cells for vehicle work use an electrolyte with density as high as 1.3. It is important to use perfectly pure acid and water, as impurities will cause local actions and ultimately destroy the plates.

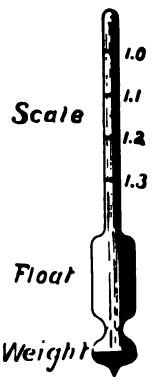


Fig. 12. The Hydrometer.

It is well to remember that water should never be poured into sulphuric acid, as it is likely to cause the liquid to be thrown out violently.

The advantage of a strong solution is its lower resistance; but it is likely to produce the very objectionable effect of "sulphating."

The density of the electrolyte falls immediately after filling a cell, since some of the acid is taken up by the plates; but it rises again in charging; for example from 1.17 to 1.2. It is convenient to keep a hydrometer in several cells to observe the density of the electrolyte, not only at the beginning, but as a permanent indicator of the amount of charge and general working conditions.

The hydrometer is an instrument for determining the specific gravity of a liquid, and consists of a weighted bulb and an upright glass rod, bearing a scale, the unit point being fixed by the distance to which it sinks in pure water at 4°C. Readings above this point are for solutions of lower specific gravity than water, and those below it are for solutions of a higher specific gravity. For storage battery work the specific gravity of the electrolyte is

always between 1.1 and 1.8, hence we require only a certain portion of the scale as represented in Fig. 12.

Charging. The charging should begin immediately after a new cell is filled with the electrolyte, otherwise the plates are likely to become "sulphated." The first charge differs from subsequent regular charges in that it should be at a rate (lower than normal) that will not cause the temperature of the cell to reach 100°F, but in all other respects it is the same.

Indications of Amount of Charge in a Storage Battery:

1. The E. M. F. rises from 1.7 volts, which is the minimum value to which a lead cell should be discharged, to approximately 2.5 volts when fully charged, although this value may be made a trifle higher or lower, depending upon the rate of charge and temperature of cell. The rise is quite gradual, but more rapid near the beginning and end of the charge, as indicated in Fig. 13. When the cell is fully charged, the E. M. F. becomes constant and the curve approaches a horizontal line as shown. The charging should then be stopped as any more energy passed through the cell is simply wasted in producing gases. The external voltage is higher in charging than in discharging because of the internal resistance of the cell and resulting I R drop, which must be overcome in charging.

The measurements of voltage should always be made when the current is flowing either in charging or discharging.

The E. M. F. on open circuit has little practical significance.

2. *If a record is kept* of the exact number of ampere hours of charge and discharge, the actual amount of energy in the battery at any time is known, due allowance being made for leakage and other losses. For this purpose any integrating instrument such as the Thompson recording wattmeter may be used.

3. *The density of the electrolyte* gradually rises during the charging operation, Fig. 13; the density when charged being about .025 higher than when discharged. There is a lag in the change of the density of the electrolyte, the acid not being absorbed or given off at once by the plates, hence a little time should be allowed before taking any hydrometer reading as final.

4. *Bubbles of gas are given off* freely when the battery is fully charged, since the material of the plates is then no longer

able to take up the oxygen and hydrogen which tend to be set free by the electrolysis; these bubbles give the electrolyte the appearance of boiling, and often they are so fine that the liquid looks almost milky white, particularly in a cell which has not been very long in use.

5. *The color of the positive plates* varies from a light brown on active parts to a chocolate color when fully charged, and to nearly black when overcharged. The negatives vary from pale

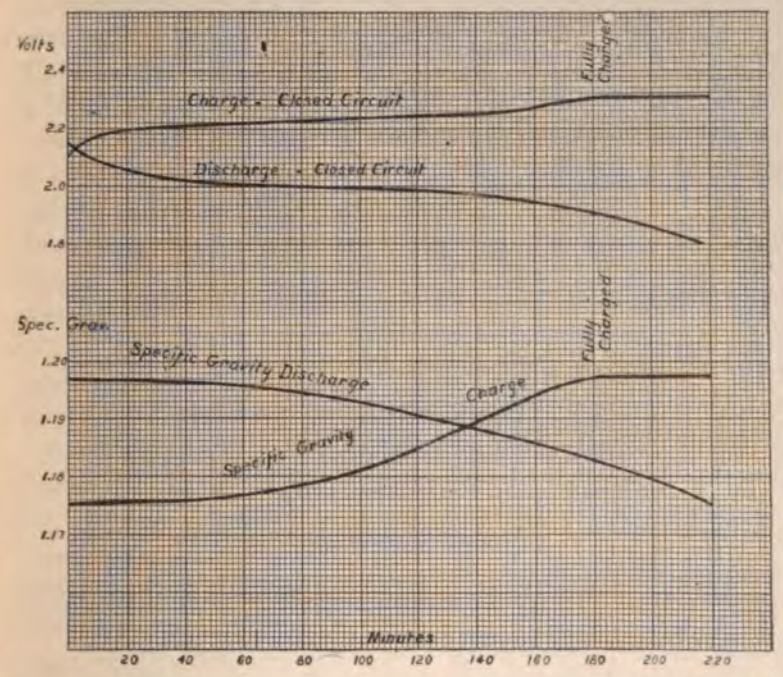


Fig. 13. Curves Showing Variations in Sp. Grav. and Voltage in a Storage Battery During Charge.

to dark slate color, but they always differ in color from the positives. This indication of the amount of charge is acquired by experience, but is quite definite after one becomes familiar with a particular battery.

6. *Cadmium Test.* The apparatus for making this test consists of a small piece of cadmium, say $\frac{5}{8}''$ x $\frac{5}{8}''$ x $\frac{1}{32}''$ mounted as in Fig. 14. A glass tube contains the conducting wire, wax being used to protect the soldered joint of copper and cadmium. Cad-

mium is used because it will give reliable readings of the E. M. F. of the positive and the negative plates, with respect to itself. In this way a relative condition of the battery and also of each plate can be determined.

With normal conditions of cell, when fully charged and in open circuit, the difference of potential between the positive and the cadmium piece is 2.5 volts or nearly so, and between the cadmium and the negative plate is zero or nearly so. In fact it is sufficient if the sum of the readings is about 2.5 volts.

To avoid false conclusions in making a cadmium test, hydrometer, temperature and charge data should be noted. The cadmium test is usually made at the center of the cell to get a uniform current distribution. This test gives readings the sum of which is less than 2.50 volts, when hydrometer tests, temperature and charge data show that the cell is not fully charged; but if the hydrometer, temperature, and other data show the charge to be completed, and the cadmium gives .1 volt or more below 2.5 volts, the defective plate is readily determined by individual cadmium readings. For example, suppose we have a cell in which all conditions tend to show full charge but the potential difference is low. A cadmium test is taken and whichever plate shows the falling off from normal reading, that plate is the defective one, and should be examined for some of the troubles that will be discussed later.

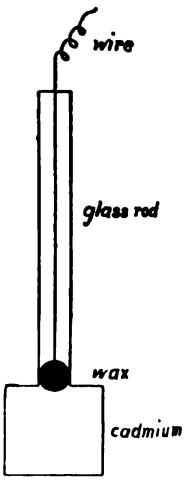


Fig. 14. The Cadmium Tester.

In some cases the cadmium reading with respect to both plates may approach zero; this is caused by a short circuit in the cell which should be found and removed immediately.

In practice it is advisable to have the cadmium wet before the test is made as the readings increase when cadmium is first placed in the electrolyte. The simplest way to accomplish this is to keep the cadmium tester in a beaker of distilled water when not in use. All foreign matter should be carefully removed from the cadmium as it might affect the results. If gas bubbles collect on the cadmium they should be taken off, as they tend to lower the readings.

The proper rate of charge depends upon the size and type of cell, and is usually specified by the manufacturer in each case, since it is merely an empirical fact, being determined by the construction of the plates.

The current for charging is ordinarily obtained from a direct current dynamo, but any other direct current source may be employed. The potential required for charging must exceed that of the battery, which, during the operation acts as a counter E. M F., the expression being $I = \frac{P - e}{R}$, in which I is the current, P the potential applied to battery terminals, e the counter E. M. F., and R the internal resistance of the cell. Usually P is 5 to 10 per

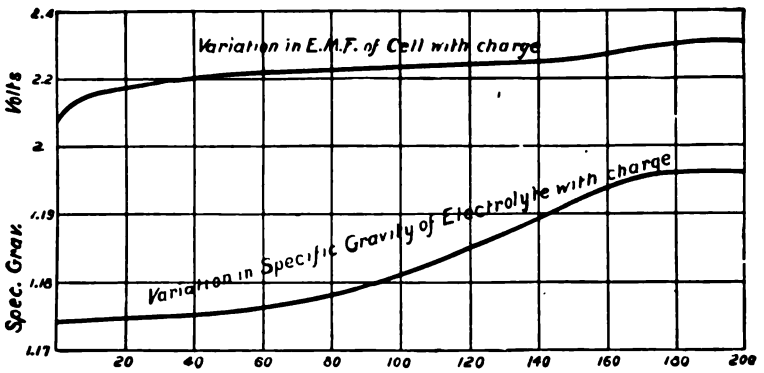


Fig. 15. Curve Showing Increase of E.M.F. in a Charging Cell.

cent greater than e, in order to cause the necessary charging current to flow through the resistance R of the cell.

In practice P is regulated until the required charging current I is obtained.

The above equation, put into form of $R = \frac{P - e}{I}$, enables the internal resistance R to be calculated, but as this varies considerably with the temperature, and with different states of charge, its exact value is not often considered.

Another form of the above equation, $e = P - IR$, shows that the true E. M. F. of the battery is less than the charging voltage by an amount equal to the product of the charging current and the internal resistance. Conversely, in discharging, the total

f cell is greater than the difference of potential P be-
terminals by the same amount, that is, $e = P - IR$.
is necessary to know I and R, or to measure the voltage
circuit is open (in which case $I = 0$), in order to find
. M. F. of cell. This applies to each individual cell as
... to the entire battery, and is important in determining the
unt of charge or working condition of a particular cell.

If the charging voltage P be kept constant, it is evident from
above equtations that the current I will gradually decrease,
...e the C. E. M. F. or e of the cell steadily rises as shown in
. 15. This effect is counteracted somewhat by the fact that
e internal resistance R also diminishes, owing to the density of
electrolyte increasing. This gradual reduction in the strength
e charging current is considered desirable by some authori-
, since it enables the cell to take a greater charge than if the
...rrent were maintained at full strength. On the other hand,
s diminishing charge makes it difficult to keep account of the
...act number of ampere hours supplied to the cell; hence in ordi-
...ry commercial work it is considered simpler to charge with a
...nstant current, and if it is desired to keep the cell temperature
down, the current is decreased near the end of the charge. The charging operation may be continued until the battery is fully charged as shown by the indications already stated. Since most types of cells are not injured by a slight overcharging at a moderate rate it may even be carried a little beyond the charged point, as it tends to remove "sulphating." A considerable overcharge should be avoided as it causes excessive formation of gas bubbles in the active materials, is likely to heat the cell and ever cause disintegration and buckling of the plates.

Discharging. A storage battery is in most cases discharged within a few hours after being charged, as, for example, in electric lighting, when the engine and dynamo are run during the day for charging the battery which supplies current to the lamps during the night. But a portable battery for feeding lamps might be required to retain its charge for several days. The loss of charge in any battery standing on open circuit is about 25% in one week, but for one day or less it is quite small.

Even when the discharge occurs immediately, the average

voltage and the ampere-hours obtained are less than for the charge, as explained under "Efficiency." The loss referred to is additional, depending upon the time.

The operation of discharging is naturally the converse of charging, the changes which have been described as occurring in the latter take place also in the former, but in the reverse order. The normal rate of discharging is usually equal to that of charging, but may be somewhat greater. In some cases it is necessary to discharge at higher rates, but by so doing a percentage of the capacity in ampere-hours is sacrificed.

For example, a cell whose normal or eight-hour discharge rate is 100 amperes, can easily be discharged at 400 amperes for one hour, but only 50 per cent of the cell's capacity in ampere-hours is obtained at the latter rate.

An excessive discharge rate is injurious to most types of storage battery plates since it tends to disintegrate the plates, and abnormally heats the electrolyte, which hastens the disintegration; it is therefore advisable to protect the battery with fuses or an automatic circuit breaker.

A storage battery *should never be discharged completely*, as it is very likely to become "sulphated," or otherwise injured; and moreover the E. M. F. falls so rapidly towards the end of discharge that the current would be of no practical value. The limit of discharge is usually considered to be the point at which the E. M. F. drops to 1.75 volts, though when cells are used at the one-hour rate the limit of discharge is 1.6 volts.

A battery should never be allowed to stand in a discharged condition, but should be recharged immediately.

The charge usually left in a storage battery is from 10 to 30 per cent of the total capacity, depending on the rate of discharge, but this involves no considerable loss of energy or efficiency, since it remains in the battery each time and the charging begins at that point.

The Efficiency of Storage Batteries. The efficiency of any apparatus is the ratio between what it gives out and that which it consumes. In a storage battery it is the ratio of the amount of discharge to what is put in to bring the battery back to its original condition after a discharge.

In the first place, the "ampere efficiency" or more properly the "ampere-hour efficiency" which is the ratio of current in ampere-hours drawn from the battery to current in ampere-hours put into the battery is quite different from the watt-hour efficiency. The latter is the real efficiency, since it considers the energy, and includes the voltage as well as the ampere-hours. Ampere efficiency may be scientifically interesting as showing the action of a battery; but it is not of much commercial importance. This is likely to be used either through ignorance or intention to give a false idea since the ampere efficiency is often 15 per cent higher than the watt efficiency.

Another difficulty with the ampere efficiency is the fact that it is possible to obtain an apparent efficiency of over 100 per cent from a storage battery. Since a certain amount (about 25 per cent) of charge is always left in the cell, it is possible to draw apparently more ampere-hours of current than were put in it, by simply discharging the cell more than usual.

This matter has been investigated by Ayrton, who states:

"If an E. P. S. accumulator be over and over again carried around the cycle of being charged up to 2.4 volts, and discharged down to 1.8 per cell, the charging and discharging currents being the maximum allowed by the makers, viz., .026 ampere per square inch of surface in charging, and .029 ampere per square inch in discharging, the working efficiency thus obtained may be 97 per cent for the ampere-hours, and 87 per cent for the watt-hours. If, on the contrary, the cell be constantly charged up before being tested, then for the first few charges and discharges between the above limits, and with the same current density in charging and discharging, even the energy efficiency may be as high as 93 per cent; whereas if the accumulator has been left for some weeks, then, although it was left charged, the energy efficiency for the first few charges and discharges will be as low as 70 per cent."

In general practice it has been found that the efficiency of storage battery plants, when in good condition, varies from 75 to 80 per cent. For instance, referring to the battery plant at the Edison Electric Company station in Boston, a series of tests made there shows the battery installation to have an efficiency of 75 per cent.

Depreciation of Accumulators. The depreciation is claimed to be as low as 5 per cent per annum; in fact both the Tudor and Chloride battery installations at the Boston Edison Company's plants are insured and kept in repairs by the makers for 4 per cent per annum of their total original cost. This figure is as low as the maintenance of the very best steam or electrical machinery. One of the largest electrical manufacturing companies in this country has in use a storage battery equipment which, for the past eight years, has not cost a cent in the way of repairs to, or renewals of, plates. On the other hand, the life of storage batteries in traction or automobile work has in some instances not exceeded six months, though it is claimed that these cells were only in an experimental stage. One must be somewhat guarded, however, in accepting low figures of this kind since from their nature the plates are very easily injured and difficult to repair. It would be very unwise for any one to purchase a battery without the makers' guarantee, to allow less than 10 per cent for its annual depreciation, and this does not include interest, taxes, or other fixed charges.

It has been the practice of several storage battery manufacturers to insure their battery equipments for 6 per cent per annum of their first total cost. This insurance is a maintenance contract calling for inspection and any repairs necessitated through normal use of cells.

TROUBLES AND REMEDIES.

The most serious troubles which occur in storage batteries are sulphating, buckling, disintegration and short circuiting of the plates. These can usually be avoided, or cured by proper treatment if they have not gone too far.

Sulphating. The normal chemical reaction which takes place in storage batteries is supposed to produce lead sulphate ($PbSO_4$) on both plates when they are discharged, their color being usually light brown and gray, due to presence of the PbO_2 still on the positive plate. But under certain circumstances a whitish scale forms on the plates, probably consisting of Pb_2SO_5. Plates thus coated are said to be "sulphated." This term is, therefore, somewhat ambiguous, since the formation of a certain

proportion of ordinary lead sulphate ($PbSO_4$) is perfectly legitimate, but the word has acquired a special significance in this connection.

A plate is inactive, and practically incapable of being charged, when it is covered with this white coating or sulphate, as it is a non-conductor.

The conditions under which this objectionable sulphating is likely to occur are as follows:

(*a.*) A storage battery may be overdischarged, that is, run below the limits of voltage specified, and left in that condition for some time.

(*b.*) A storage battery may be left discharged for some time, even though the limits have not been exceeded.

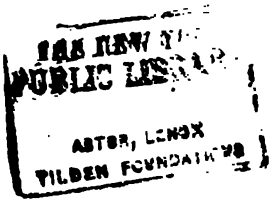
(*c.*) The electrolyte may be too strong.

(*d.*) The electrolyte may be too hot (above 125° F).

(*e.*) A short circuit may cause "sulphating" because the cell becomes discharged (on open circuit) and when charging it receives only a low charge compared with the other cells of the series. A battery may become overdischarged or remain discharged a long time on account of leakage of current due to defective insulation of the cells or circuit, or the plates may become short-circuited by particles of the active or foreign substances falling between them.

Sulphating may be removed by carefully scraping the plates. The faulty cells should then be charged at a low rate (about one-half normal) for a long period. In this way, by fully charging and only partially discharging the cells for a number of times, the unhealthy sulphate is gradually eliminated. When the cells are only slightly sulphated, the latter treatment is sufficient without scraping; when the cells are very badly sulphated, the charge should be at about one-quarter the normal rate for three days.

Adding to the electrolyte a small quantity of sodium sulphate, or carbonate, which latter is immediately converted into sodium sulphate, tends to hasten the cure of sulphated plates by decomposing or dissolving the unhealthy sulphate. This is not often used in practice, as a cell must be emptied, thoroughly washed and fresh electrolyte added after the plates have been restored to their proper condition before the cell can be used to advantage.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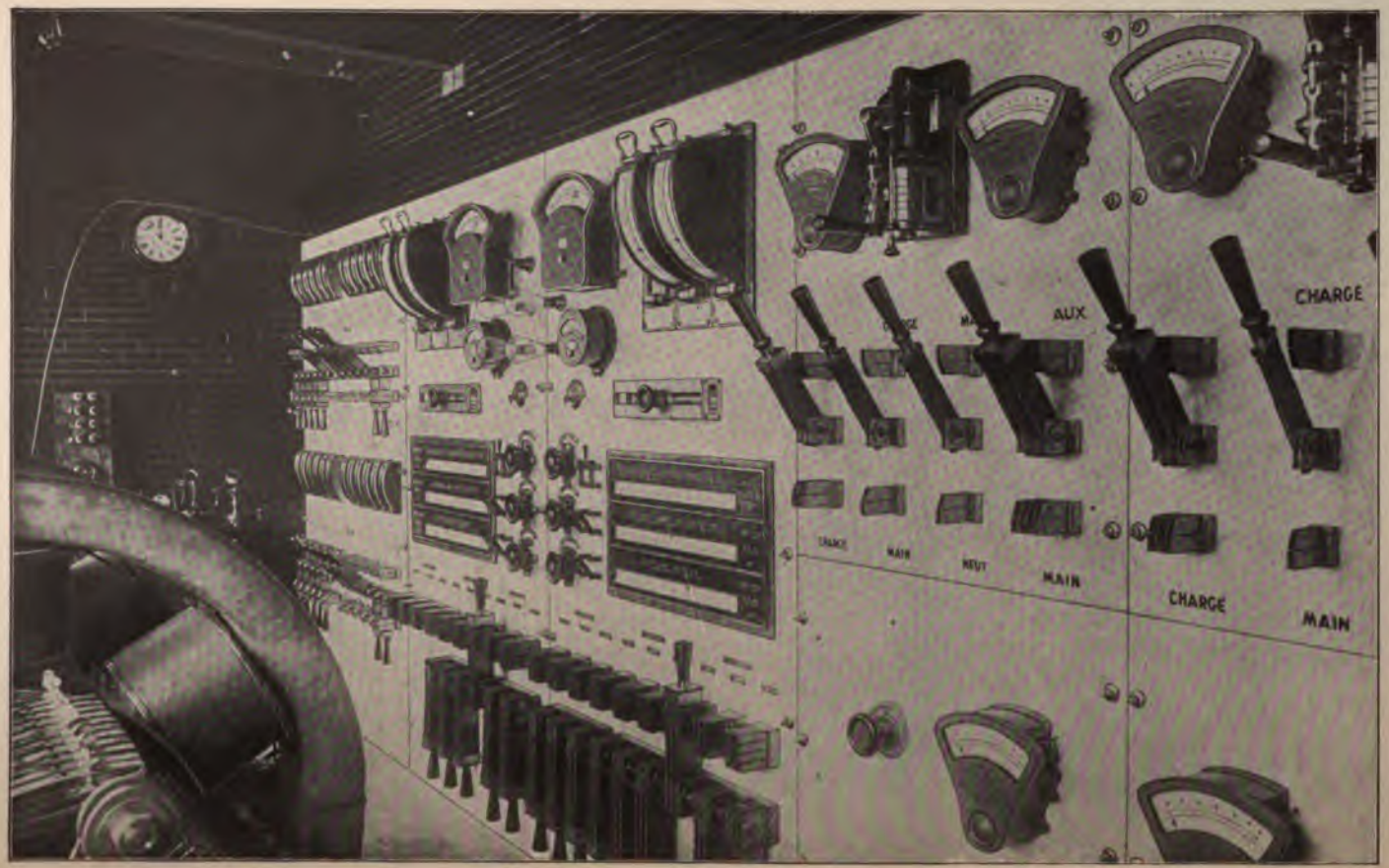


Storage Battery Switchboard

Detroit Edison Company

Sulphating not only reduces the capacity of lead storage batteries, but also uses up the active material by forming a scale which falls off or has to be removed. It also produces the following trouble:

Buckling, or warping of a plate, is caused by uneven action on the two surfaces; for example, a patch of white sulphate on one side of a plate will prevent the action from taking place there, so that the expansion and contraction of the active material on the other side, which occurs in normal working, will cause the plate to buckle. This might be so serious that it would be impossible to straighten the plate without breaking or cracking it; but, if taken in time, it may be accomplished by placing the warped plate between boards, and subjecting it to pressure in a screw or lever press. Striking the plate is objectionable, because it cracks or loosens the active material; but, if it should be necessary to straighten a plate in this way, a wooden mallet should be used very carefully, with flat boards laid under and over the plate. Buckling may be caused by an excessive rate of charging or discharging, as well as by sulphating.

Disintegration. Some of the material may become loosened or entirely separated from the plates, as a result of various causes. The chief of these is sulphating, which forms scales or blisters that are likely to fall off, thus gradually reducing the amount of active material and the capacity of the cell. Buckling also tends to disintegrate the plates. Contraction and expansion of the active material may take place in normal working, and are increased by excessive rates or limits of charging and discharging. This constitutes another cause of disintegration, particularly in plates of the Faure type containing plugs or pellets of lead paste.

The fragments which fall from the plates not only involve a loss of material, but are also likely to extend across or gather between the plates, and cause a short circuit

The positive plates are far more susceptible to and injured by these troubles than the negatives. The former are also more expensive to make, therefore it is to them that special attention should be directed in the management of storage batteries.

Short Circuiting of cell may be caused by conditions previously stated and also by the collection of sediment at the bottom

of the containing cell. The short circuiting caused by the dropping in of foreign matter, or the bridging of the active materials, is prevented by the use of glass, rubber or wooden separators

The short circuiting of plates by the formation of sediment is prevented, or the chances of it are decreased by raising the plates so that they clear the bottom of the containing cell. In small batteries this clearance is about an inch, in large cells it is considerable, being about 6 inches, and on account of the weight of large sized plates they are supported at the bottom by glass frames running lengthwise through the cell, as shown in Fig. 16.

This sediment should be watched carefully and when it reaches a depth of 1 inch or more at the center of the cells, it should be removed. The usual method is to take out the plates, syphon the electrolyte off carefully, and then flush out the tanks until all the sediment is removed. If syphoning cannot be resorted to, due to absence of drop, a pump may be used, either of glass or of the bronze rotary type.

Troubles from Acid Spray. An accumulator gives off occasional bubbles of gas at almost any time or condition; but when nearly charged, the evolution becomes more rapid. These bubbles, as they break at the surface, throw minute particles of acid into the air, forming a fine spray which floats about. This spray not only corrodes the metallic connections and fittings in the battery room, but is also very irritating to the throat and lungs, causing an extremely disagreeable cough.

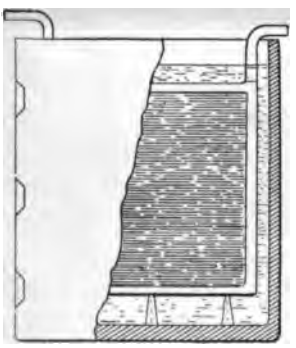


Fig. 16. Glass Frame Support Used to Prevent Short Circuiting by Sediment.

Glass covers are sometimes placed over cells to prevent the escape of fumes, but this is not advisable as the glass becomes moist and will collect dust, thus forming a conducting surface over the cell.

Attempts have been made to do away with this spraying by placing an oil film (thin layer of oil) over the electrolyte, but this has the objection of interfering with hydrometers; in addition it sticks to the surface of the plates when they are removed, and interferes with their conductivity on replacing them.

Another plan consists of spreading a layer of finely granulated cork over the surface of the liquid, but while this does not interfere with the hydrometer, it makes the cell look dirty.

The general practice is to depend almost entirely upon ventilation to get rid of the acid fumes, in fact, even forced ventilation is used. A blower forces fresh air into the room, which is provided with a free exhaust.

In connecting up the cells, it is advisable to use lead-covered copper cables, as this covering protects the copper, and prevents the formation and the dropping of copper salts into the cell.

The Purity of the Electrolyte is very important, and great care should be taken to insure it. The electrolyte may have nitric acid present when "formed" (Planté) plates are used, and some chlorine, when "Chloride" negatives are used. In addition, iron may be present due to the water or acid; if the sulphuric acid is made from iron pyrites; it may also be present, owing to the corrosion of iron fittings near the cells, some of the scale falling into the electrolyte. Similarly some of the copper salt formed from the connections by this corrosive action may fall into the cell. Mercury may also be present due to the breakage of hydrometers or thermometers.

Other foreign substance might be present, but those named are the most harmful.

Nitric acid, even in exceedingly small quantities, will cause disintegration of plates, as the supporting material is destroyed.

Chlorine has a similar effect.

Iron, mercury and copper produce local action, and thus decrease the efficiency and ultimately the life of the cells.

The electrolyte should be tested about once a week for these impurities, and if any of them are present, it should be drawn off and renewed. If nitric acid is present, it is even advisable to flush the cell with pure water.

TESTS.

1. **Test for Chlorine.** To a sample of electrolyte in a test tube, add a few drops of silver nitrate solution; if a curdy white precipitate forms, an excess of ammonia is added, and if this dissolves the precipitate, chlorine is present in some form.

2. **Test for Iron.** Iron may appear in one of two forms, namely, ferrous or ferric salts. A small sample is taken and some concentrated hydrochloric acid added and then some potassium ferric cyanide; if a heavy blue precipitate forms, ferrous iron is present; if in very minute quantities, a deep blue green discoloration results.

3. **Test for Ferric Salts.** To a sample add some ammonium thio cyanate; if a blood red solution or precipitate is the result, ferric iron salts are present.

4. **Test for Copper.** To a sample of electrolyte an excess of ammonium hydrate is added; if a rich blue solution is the result, copper is present. It is advisable to check the test by taking another sample and adding some potassium hydrate to it; if a blue precipitate is found which turns black upon boiling, it is additional proof of the presence of copper.

5. **Nitric Acid** being injurious even in very small quantities, it is advisable to make the following test, which is very sensitive. Some diphenylamine in concentrated sulphuric acid is added to the sample; if a deep blue color is the result, nitrates or nitrites are present.

6. **Test for Mercury.** Mercury may be present in two forms, mercurous or mercuric compounds. The *mercurous* compounds give a black precipitate with lime water, and a greenish precipitate with potassium iodide.

The *mercuric* compounds give a yellow precipitate with lime water, and a red or scarlet precipitate with potassium iodide.

On account of possible difficulties with these various impurities the following is recommended:

1. Test every carboy of sulphuric acid before using.

2. Concentrated sulphuric acid should not be kept around, as it may be used by mistake, which would ruin the plates.

3. Only distilled water from carboys should be used and not from barrels, as it may be contaminated from the organic material of the barrels.

4. Water from the city mains is never to be used unless the amount of impurities which it contains is very small.

5. When testing with hydrometer for specific gravity, the battery should be fully charged and the temperature constant.

Quantitive tests are generally necessary.

Putting the Battery out of Commission. If, for any reason, the battery is to be but occasionally used, or the discharge is to be at a very low rate, a weekly freshening charge to full capacity at normal rate should be given.

It frequently happens in practice that a storage battery equipment is put out of commission for a lengthy period, (for instance, in most summer or winter resorts the battery may be used for one half of the year only). In such cases the procedure is as follows: First give the battery a complete charge at normal rate, then syphon off the electrolyte into carefully cleaned carboys (as it may be used again), and as each cell is emptied, immediately refill it with pure water. When the acid has been drawn from all cells and replaced with water, begin discharging the battery and continue until the voltage falls to or below one volt per cell at normal load (rate); when this point has been reached the water should be drawn off. In this condition the battery may stand without further attention until it is to be again put into service, and to do this proceed in the same manner as when the battery was originally put into use.

If during the discharge, when the water has replaced the electrolyte, the battery shows a tendency to get hot (100°F,) add colder water.

Commercial Application. The function of a storage battery is to receive electrical energy at one time or place, and to give it out at some other time or place.

The principal uses are the following:

1. To furnish portable electrical apparatus with power.

2. To make up for fluctuations, and thus steady the voltage and load on the generator.

3. To furnish energy during certain hours of the day or night, and enable the generating machinery to be stopped.

4. To aid the generating plant in carrying the maximum load (peak) which usually exists for only an hour or two.

5. To make the load on engines or prime movers more uniform, by charging the battery when the load is light.

6. To transform from a higher to a lower potential by charging the cells in series, and discharging them in parallel, or vice-versa.

7. To subdivide the voltage, and enable a three or a five wire system to be operated from a single generator.

Fig. 17. Gould Portable Storage Battery.

8. To supply current from local centers or substations.

9. To supply current to electrically driven vehicles.

10. As sources of current in telephone and telegraph systems.

11. For car lighting purposes.

12. As sources of constant potential and current in electrical laboratories.

Portable Storage Batteries. The storage battery is practically the only means of supply for portable electric lamps, or those not connected to a dynamo even when they are not portable. The primary battery is expensive and troublesome to operate; and has never been commercially successful for electric lighting or power, except where only a very small amount is required. Nor is there any other satisfactory primary source of electrical energy except the dynamo driven by mechanical power. It is therefore practically essential to adopt storage batteries wherever portable electric motors, lamps, etc., are used.

The various manufacturers furnish portable forms of storage batteries: for example, the Gould Storage Battery Company's portable battery (Fig. 17) is arranged in a case made as a hard rubber jar, lead-lined box or glazed earthenware jar, over which is placed a rubber gasket, and then a wooden cover clamped in place by U shaped straps, passing around the containing vessel. For ventilation in charging, the cover has threaded holes which, when the battery is in use, are closed with hard rubber stoppers. The usual number of cells in a case is from one to five, although they are made up in larger numbers if desired. The batteries are rated at 2 volts per cell.

A serious objection to portable storage batteries is their great weight. For example, a standard size weighing 60 lbs. yields 5 amperes at ten volts, or fifty watts for ten hours: just enough to feed a 16 C. P. lamp. The total discharge is 500 watts-hours or two thirds of one H. P.-hour. The special forms of battery used in automobiles give about twice this output for the same weight.

This weight is almost prohibitive to portability except for automobiles, railway train lighting and special purposes.

Portable batteries, for example, are used for feeding small motors, lamps etc. for medical or dental purposes, in which cases their weight is not a serious difficulty in view of the importance

of the work, and the small amount of energy required. Another special field for very small batteries is the theatrical application for which they are carried by the performers. Storage batteries are also being extensively used as source of power to drive small fan and kinetoscope motors.

Storage Batteries for Preventing Fluctuations due to unsteadiness in the driving-power or in the load, as with elevators, are often applied successfully. A dynamo driven by a gas-engine, for example, may vary periodically in speed because of the explosive action of the gas in the cylinder; and a battery connected in parallel with the dynamo will have the effect of steadying the voltage. A storage battery is generally installed in connection with a small gas or steam engine lighting plant to enable the engine to be stopped for a considerable portion of the time, and thus save labor and attention, in which case the battery may also act to prevent fluctuations. A windmill electric-lighting plant must have an accumulator or some other means of storing energy, not only to eliminate fluctuations in speed which are continually occurring, but also to bridge over the considerable periods of calm weather.

To Furnish Energy During Certain Portions of the Day or Night. In almost every electric-lighting plant, there are long periods during the day and late at night when the number of lamps lighted is so small that it may not pay to run the generating machinery.

For example, Fig. 18 is a load diagram showing the weekly output of the electric plant of the Astor Building in New York City. The generator plant runs from 3 A.M. to 8 P.M. each day, the battery being charged from 3 A.M. to 11 A.M.; and when the generating plant is shut down at 8 P.M. the battery carries the entire load from then until 3 A.M., when the plant is started up again. Saturday nights the plant is shut down at eight o'clock, and the battery furnishes all the power required from then until Monday morning at 3. This enables the plant to be operated by two gangs or shifts; practically no labor being required for the remaining seven hours as the battery carries the load, and the machinery is stopped entirely all day Sunday, giving a stretch of thirty-one hours once a week and seven hours each

night for cleaning and repairs. In a hotel, residence or on board a yacht, it may be desirable to stop the machinery and avoid the vibration and noise during the night.

Storage Batteries to Aid in Carrying the Maximum Load. Assume in the case of the load diagram shown in Fig. 19, that the generating machinery is capable of supplying 8,000 kilowatts and that a storage battery is used to furnish the remaining 3,600 kilowatts at the time of maximum load, that is, the "peak" of the load diagram. This simply means that batteries are substituted for a certain portion of the machinery plant, and the question is whether or not the substitution is of any advantage.

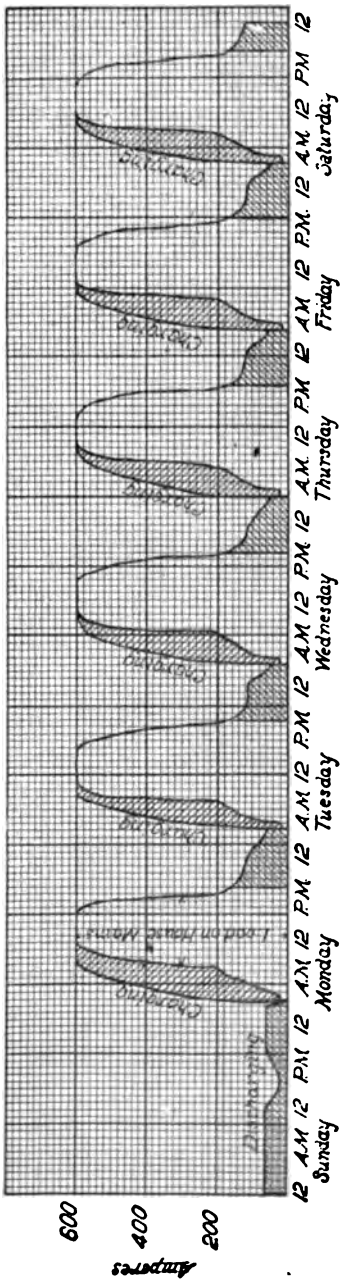

12 AM 12 PM 12 AM 12 PM 12 AM 12 PM 12 AM 12 PM 12 AM 12 PM 12
Sunday Monday Tuesday Wednesday Thursday Friday Saturday
600
400
200
Amperes

Fig. 18. Load Curve of Astor Court Building.

The first cost of a battery for a given rate of output depends simply upon the time of discharge. Batteries usually have a normal period of discharge of about 8 hours, at which rate the price of accumulators to furnish a given number of watts would be 3 to 5 times as great as that of the equivalent boilers, engines and dynamos combined, but if the time of discharge is reduced to about 2 or 3 hours, the costs are about equal and with a still higher rate the cost of batteries would be less.

As a matter of fact, the storage battery secures other advantages so that the total gain may be very important. For example, there is a reserve supply in case of accident and the load may be made more uniform as will now be explained.

Storage Batteries to Maintain Uniform Load on Engines. Steam engines are very inefficient at light loads, and this fact often causes serious losses especially in electric-lighting plants. Judicious selection of the number and sizes of the engines enable them to be worked in most cases at a considerable fraction of their full capacity nearly all of the time. Nevertheless, the storage battery gives greater flexibility to the plant, and renders it easy to increase the economy of the engines by making their loads

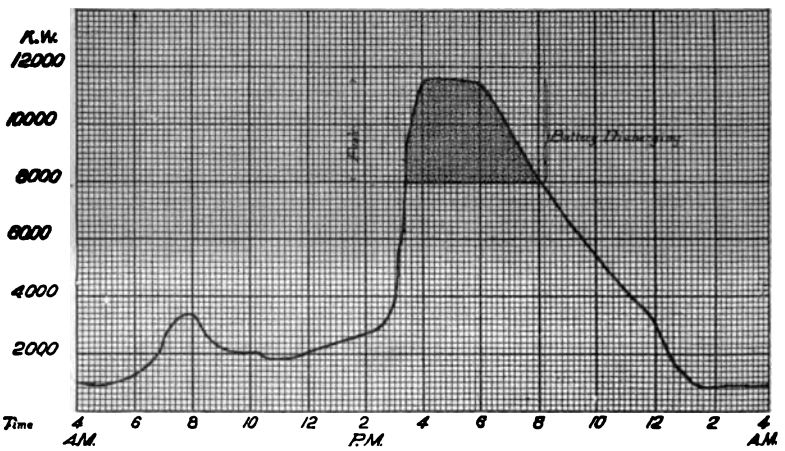


Fig. 19. Load Curve Showing "Peak" of Load Carried by Storage Battery.

still more uniform, and nearer to their full capacities while they are running. The engines can be made to have a uniform full load, the battery being charged when the external load is light, and the battery taking the peak of the load when it is heavy.

Storage Batteries Used as Transformers. If the cells of a battery are arranged in series while being charged, and in parallel for discharging, a high voltage will be required for charging, and a low voltage will be given out. The amounts of energy measured in watt hours are the same, less the loss of about 25 per cent which always occurs in accumulators; the result is similar to that obtained by an alternating current transformer or motor-dynamo

but is less efficient. As an example the equipment used at the Brooklyn Navy Yard may be mentioned. It consists of about 250 small cells connected up in series parallel of 5 sets of 50 cells each and charged on a 110 volt circuit. When discharged they are connected up all in series and give about 500 volts but with very small current. This equipment is used to furnish 500 volts for the "insulation test" of cables and therefore requires little or no current.

Storage Batteries Used for Subdividing Voltage. The most important practical case is that in which a dynamo of 220 volts charges a battery of corresponding potential, a three wire system being supplied from the battery, the neutral wire of which

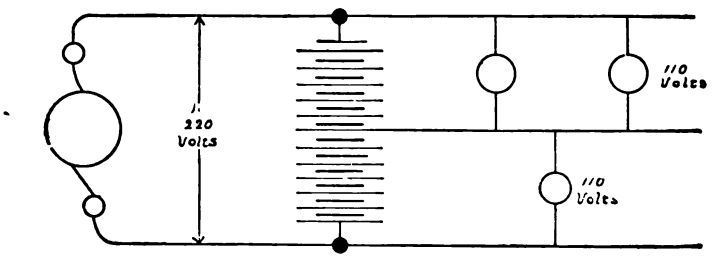


Fig. 20. Battery used to Sub-divide Voltage.

is connected to the middle point of the battery as represented in Fig. 20. This arrangement avoids the necessity of running two dynamos, and allows the battery to be placed in a sub-station near the district to be supplied, so that it is only necessary to run two conductors to that point instead of three. The same principle may be applied to the five-wire system.

The Hartford Electric Light Company was one of the first in this country to introduce the modern method of high tension transmission, with low-tension 3 wire distribution.

The auxiliary battery used in connection with this equipment consists of 130 Chloride Accumulators (65 on a side) each cell containing 31 negatives and 30 positive plates, each $15\frac{1}{2}''$ x 31", placed in lead-lined tanks measuring $58\frac{1}{4}$ x $21\frac{1}{2}$ x $43\frac{7}{8}$ inches. Fig. 21 is a diagram showing the general plan of the system. The power is transmitted 10.8 miles from the Farmington River

Power Station to the Pearl Street Station, in Hartford, by means of step-up transformers, a ten thousand volt transmission line, and step-down transformers for distribution. From Pearl Street Station to State Street, a distance of three thousand feet, the current is transmitted at twenty-four hundred volts, at which latter point, by means of step-down transformers and rotary converter, the storage battery is charged and the current distributed over a low tension three wire system.

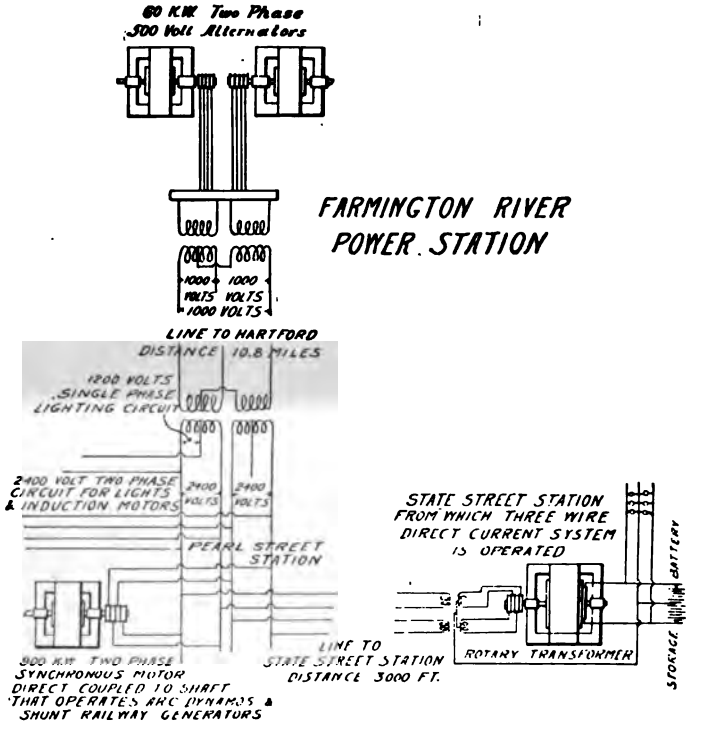


Fig. 21. Plan of the Farmington River — Hartford Distribution System.

Storage Battery for Sub-Stations. The plan of installing battery plants at local centers, which are charged from the main station, enables some of the conductors to be saved in a three (or five) wire system, as already stated. It also makes it possible to reduce the size of these conductors, because the current which flows over them can be kept practically constant, so that it is not necessary to have them large enough to carry the maximum cur-

rent consumed by the lamps, etc. which may be several times its average value. The generating machinery has the same steady load as if the battery were located near it.

The batteries at the various sub-stations may be connected and charged in series or in parallel. The former plan would require far less copper in the conductors since the voltage is multiplied by the number of batteries in series, and the current is the same as for a single battery. On the other hand, this great difference of potential would exist between the first and the last batteries of the series and if either of these became grounded, any person connected to the earth and touching a wire supplied by the other battery would receive a shock due to the total voltage.

An excellent example of the storage battery sub-station is the Bowling Green Plant of the New York Edison Company the description of which is as follows: The Bowling Green Station furnishes an auxiliary supply of current directly from the battery, enabling the feeders, extended as tie feeders into the Bowling Green building, to be used as distributing feeders to the system from both the Duane Street and Bowling Green Stations. While acting as an auxiliary supply to the general system, the battery also takes care of the distribution of current to the extensive installation in the Bowling Green Building itself. The supply of current to charge the battery is taken from the Duane Street Station, about a mile distant, over four tie feeders equipped with controllable disconnective switch boxes on the Bowker-Van Vleck system. This enables them to be used as tie feeders by disconnecting them from the general system during the hours of light load, and as distributing-feeders during the hours of maximum load, when they feed current into the system from each end. A considerable saving is thus effected in the investment because costly feeders are not required to supply the maximum load to a distant part of the system.

This installation of an auxiliary source of current supply in the lower district makes it possible to shut down the generators in the Duane Street Station during the hours of maximum load, the supply of current to the district [illegible] being derived from the battery plants at Bowling Green and 13th Street Stations, supplemented [illegible] by the supply of current from

the 26th Street Station over the tie lines to 12th Street Station, whence the current is distributed through boosters raising it to the required potential, over the tie feeders to the Duane Street Station switch board. The battery and operating rooms of the Bowling Green Station are located in the sub-basement of the Bowling Green Office Building. Vitrified hollow tile for conducting the feeder cables are laid under the battery room floor, which consists of glazed white tile. Drains to carry off the water or acid run in the aisles between the cells and lead to small cesspools which discharge into a lead drain pipe.

The battery consists of 150 Chloride cells, seventy-five in series on each side of the three wire system. The cells consist of wooden tanks, 40¾ by 21½ by 30½ inches, treated with an acid proof paint and lead lined, each containing 14 positive and 15 negative plates 15½ inches wide by 31 inches high. Each tank is supported on four petticoat porcelain insulators resting upon 6-inch glazed tiles.

The plates are suspended in the tanks by shoulders resting upon sheets of heavy glass, which stand upon lead saddles in the bottoms of the tanks. The cells are connected by welding the plate terminals to lead bus bars, no mechanical connections being used.

Twenty of the end cells on each side of the system are used for regulating; being separately connected to contact points on the regulating switches, which carry movable contacts operated by a screw. The potential is raised or lowered by cutting in or cutting out the regulating cells. Two regulating switches are connected in multiple on the positive and two on the negative sides to permit of discharge at two potentials, or to enable the battery to be charged and discharged simultaneously. The conductors between each series of cells, and between the regulating cells and the regulating switches, consist of copper bars 3 inches wide by ¼ inch thick. These bars are supported on porcelain insulators resting in hangers.

The connections of this equipment are shown in Fig. 22.

The capacities of the battery at various rates of discharge are:

2000 amperes per side for 1 hour.
1000 amperes per side for 3 hours.
400 amperes per side for 8 hours.

Provision has been made in the battery-room for the installation of a duplicate battery, which can be placed over the present plant. The booster is used to raise the voltage from that of the system to that required for charging the battery. The booster can be used also to raise the voltage of discharge for feeding some distant point of the system at a higher potential than would be normally required. The machine consists of one positive and one negative dynamo at each end of a common shaft driven by two

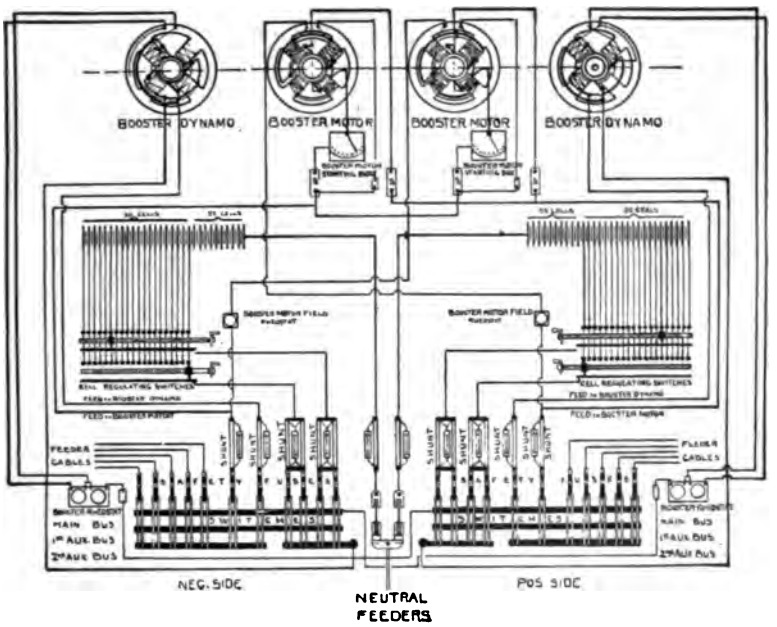


Fig. 22. Connections of the Bowling Green Storage Battery Sub-station.

motors. Each dynamo has a capacity of 1200 amperes and a range of pressure up to 60 volts.

Storage Batteries Used for Two or More of the Above-named Purposes. Each of the different uses has been considered separately to avoid confusion, but in most cases the storage battery is adopted in order to secure several advantages. By thus combining different applications the plant is rendered not only more economical, but also more flexible. For example, the battery may be utilized to help out the generating machinery at times of heavy load, or when the latter is partially or wholly dis-

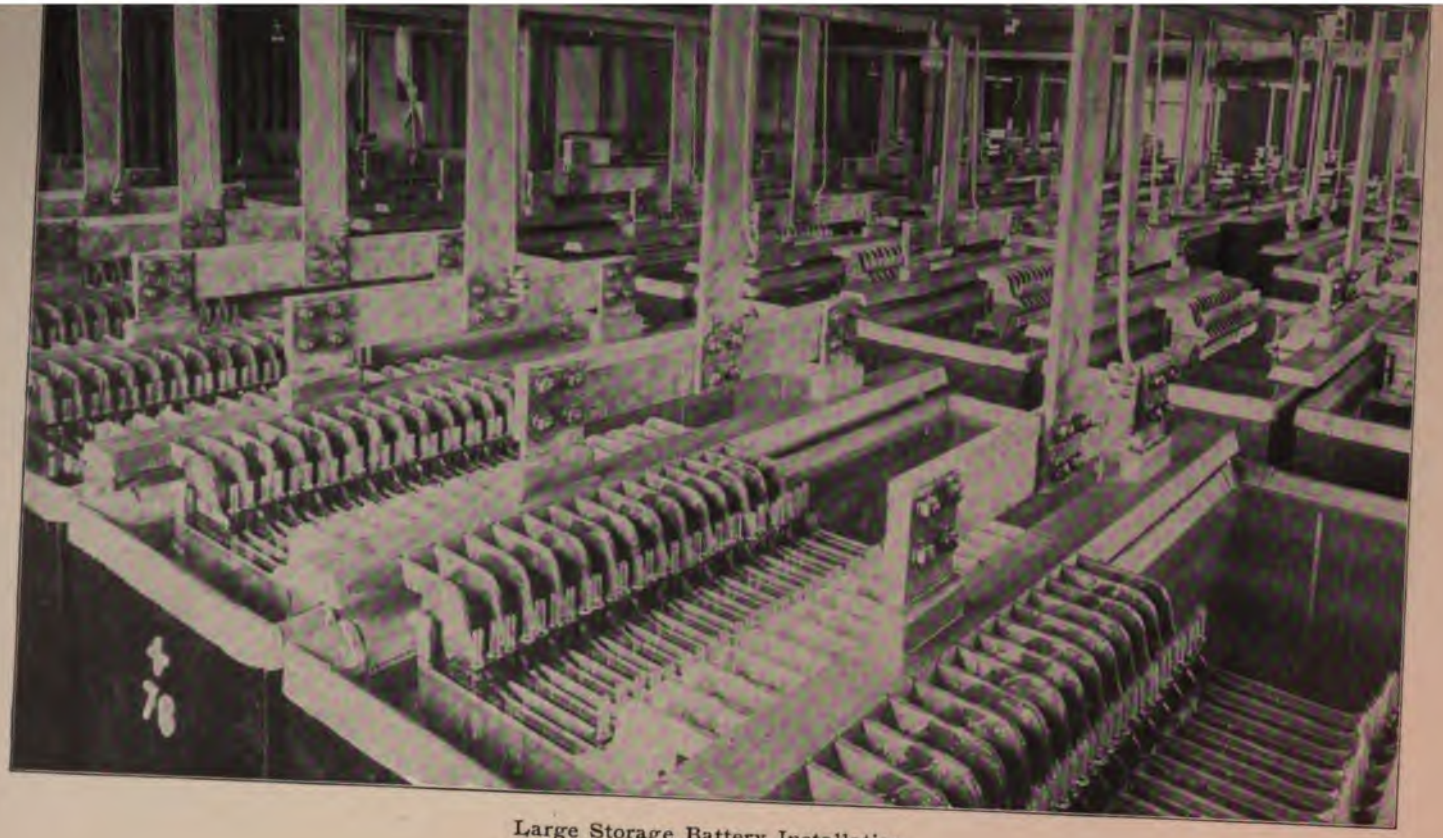
abled. It often happens that it is difficult to produce or maintain sufficient steam-pressure, owing to poor draft or other conditions, in which event a battery enables the boilers to be temporarily relieved of some or all of the drain upon them while the pressure is being raised to the proper point. It may also be necessary or desirable to shut down the machinery or a portion of it, temporarily, in order to make some repair or adjustment. It is also possible to feed some of the circuits from the battery while the others may be supplied at a higher or lower voltage by the machinery. In these and many other ways the storage battery may be a convenient adjunct to an electrical system. The fact that it is so radically different from the machinery in its nature and action makes it very unlikely that the entire plant will be crippled at any one time, since the two sources of current are not exposed to the same dangers. An accident to the steam-piping, for instance, might shut down all the machinery, but probably it would not affect the battery; and, vice-versa, an accident to the latter is not likely to extend to the former.

As an example of this application of the storage battery to several purposes, the following case may be cited:

The installation of storage batteries at the power house of the Woronoco Street Railway Company, in Westfield, Mass., presents features of special interest. After considering various methods of increasing the power-house capacity, rendered necessary by the construction of an extension of the line, it was decided that the storage battery offered the greatest advantages.

The station equipment consists of two 75-KW. multipolar generators belted to two 120 H.P. high-speed, simple, non-condensing engines, steam being furnished by two 90 H.P. return tubular boilers.

The battery consists of 264 cells of the "Chloride Accumulator," Type F–11, in glass jars of Type F–13, permitting an increase of 20 per cent by the addition of one pair of plates in each cell, and is installed in a small brick extension to the power house. The cells are located in one tier, each cell being supported on a sand tray resting on four glass insulators. The foundation for each row of cells consists of two stringers of wood su braced and supported on brick piers. This battery was no



Large Storage Battery Installation

St. Paul Gas Light Company

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stalled as a voltage regulator, the feeder system being so designed that the drop on the line is only a small amount.

By means of the battery the load on the machinery is reduced within the capacity of one unit, leaving the second one as a reserve in case of an accident or an unusually heavy load. Without the battery both machines would be needed nearly all the time.

The economy of operation, due to using one unit instead of two, is clearly shown by the following station records.

	Date, 1899.	Lbs. coal.	Output kw.-hrs.	Lbs. coal. per kw.-hr.
With battery	Oct. 25-27	16,250	3,032	5.36
Without battery	Oct. 28	6,250	981	6.37

This shows an increase in the coal consumption of 19 per cent. on the day when the operation of the battery was discontinued. The plant is also noteworthy from the fact that the station attendance is reduced to one man per shift, the engineer doing his own firing. This arrangement could not have been continued under the conditions of increased load, had it not been for the improved regulation and reduction of coal handling, and especially the increased reliability of operation secured by the battery.

On several occasions the battery has been called upon to carry the entire load of the system for an hour or so, during a temporary shut-down of the rest of the plant, as well as early in the morning or late at night, when only one or two cars are in operation.

Storage Batteries for Propelling Vehicles and Boats. The storage battery is usually about 35 per cent of the total weight in the modern electric automobile, and even with this great proportion, the distance run on one charge is seldom more than from 20 to 40 miles at a speed of about ten miles per hour, and that only on comparatively smooth roads. The battery equipment varies in different types of vehicle, but is generally 24, 36, or 44 cells and of a capacity in proportion to the size of the vehicle.

In cities or where the roads are good, with charging stations close at hand, the electric automobile is superior to the gasoline types, on account of the absence of explosive vapors, with the accompanying odor and noise. But for general touring they are not as handy on account of the limited capacity of the battery.

The application of the storage battery to the street car, while presenting such great advantages as the entire absence of poles and overhead wires, has not been a commercial success, mainly on account of the mechanical weakness of the plates, which are not able to stand the jolting and jarring or the rush of current due to frequent starts and stops. Another objectionable feature was the escape of acid fumes into the car, producing throat irritations and coughs among the passengers, although this was overcome by the use of fans.

The storage battery has been comparatively successful as a source of power in submarine boats, being charged while the vessel is on the surface, and discharged to run electric motors and lights when the vessel is manœuvering under the surface.

Storage Batteries in Telephone and Telegraph Systems. Since the adoption of the central battery systems by telephone companies, the use of the storage battery for this purpose has become very common, its advantages over the primary cell being as follows: Lower first cost, smaller space required (about $\frac{1}{4}$ of that occupied by an equivalent primary battery), greater constancy of E. M. F. and lower internal resistance, absence of the annoying "creeping salts," and rapidity of recharge. The cost of storage battery maintenance is about $\frac{1}{8}$ that of the primary cell.

In telephone work, the battery is installed in the district station, and charged when the line is not in use, from either a street connection or a generator in the station. When the line is in use for conversation, the charging current is automatically cut off, and the battery alone switched into service.

The storage battery in telephone work has become so important that the following description of a typical installation is given.

In the Filbert Street Exchange of the Philadelphia Bell Telephone Company there are two generating units, forming a duplicate plant, each consisting of one engine, directly connected to a 30 K. W., 110 volt dynamo. These machines are run on alternate days and are used for lighting the building and for furnishing power at 110 volts to various motor generators. The latter comprise two 1.5 K. W. machines for charging a 20-volt battery, one 1.5 K. W. machine for charging an 8-volt battery; one 500-watt machine for charging a 4-volt battery, and two $\frac{1}{4}$ H. P. 75-volt

alternating current motor-dynamos for ringing call bells. Only one machine is installed for the 8-volt battery and one for the 4-volt battery. Both batteries are in duplicate. To avoid a possible break down, a rheostat is furnished, so that tne batteries of lower voltage can be charged from batteries or motor-generators of higher voltage. All machines are protected by automatic cut-outs.

The 20-volt battery consists of ten "Chloride Accumulators" having a capacity of about 1,000 ampere-hours, which furnish all the current needed by the subscribers for talking and for calling up the central office. The 8-volt batteries, in duplicate, consist of four cells each having a capacity of 2,400 ampere-hours. This battery furnishes current for the "disconnect" signals on the operator's cords, and for the relays which cut out the subscriber's lamp signal when the operator answers his call, by plugging into the jack corresponding to the lamp signal.

Half the drop in potential of the 8-volt battery is in the 4-volt lamp, and the other half in the cut-out relay. This battery is in duplicate, so that one can be charged while the other is being discharged. This avoids danger of burning out the lamps, as the voltage of the battery is raised from 8 to 10 volts during charging.

Each of the duplicate 4-volt batteries comprises six 13-cells arranged in two sets. One of these sets consists of four cells, two in series, two in multiple; the other of two cells. The two extra cells are needed on one of the batteries to supply current for the operator's transmitters. The latter is arranged to furnish a current of four volts or two volts as desired. The 4-volt battery also furnishes all current for the lamp signals which light when a subscriber takes his telephone off the hook. This lamp is put out when the operator answers the call. This battery also is made in duplicate, one being charged while the other is discharged, to avoid burning out the lamp from the higher voltage during charge.

Storage Batteries for Train Illumination. When cars are lighted by oil or gas lamps, these, owing to their size, and the heat produced by them, can be installed only in certain places, so that the distribution of light is not general, besides which, the heat and odor given off by the lamps are objectionable. The in-

flammable character of the illuminants involves great danger of explosion or fire in case of a train wreck. The absence of these disagreeable and dangerous features in electric lighting, is what has made its application so desirable in traction work.

Several methods of electric illumination have been tried on railroad trains. In one of the simplest of these a small dynamo, on the locomotive truck, or one perched above the boiler, is driven by a small steam turbine. While this is an economical method, it has the objection, that when the locomotive is uncoupled, the cars must be illuminated by some other means.

For this reason, the storage battery system of supply has been adopted. A description of one of the most successful meth-

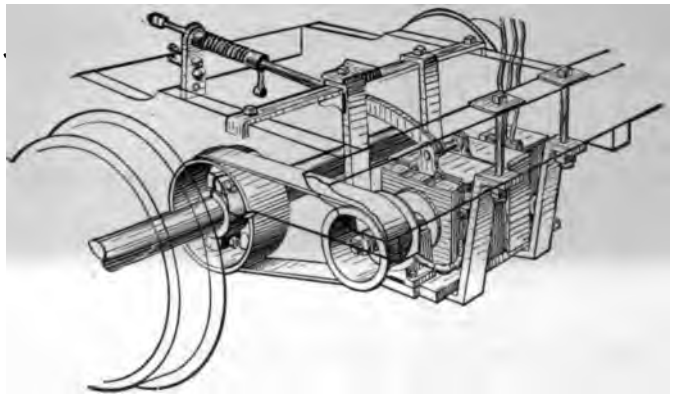

Fig. 23. Method of Suspension Used by the "Axle Light" System.

ods is as follows: The "Axle Light" System, as its name implies, derives the motive power for its dynamo from the car axle. The mechanism is suspended from the bottom of the car, and is completely encased, so as to be dust and water proof. It comprises a small dynamo driven from a pulley on the axle of the car by means of a friction coupling.

The dynamo and driving mechanism are shown in Fig. 23. The former generates from 32-40 volts, depending upon the speed of the train provided that it exceeds 15 miles per hour, the dynamo being then automatically connected to the battery and lamp circuit. An automatic device rectifies the direction of current, so that even though the direction of rotation is reversed, the battery

is always charged in the proper direction. A variable resistance in series with the field coils is automatically adjusted by a small motor, so that even at high speed the normal limit of voltage is not exceeded.

The lamps are 16 C. P. at 30 volts, the filaments being short and heavy so that they are not injured by vibration.

After the storage battery has been charged, it acts in parallel with the dynamo and avoids fluctuations in voltage. When the car stops, the dynamo is automatically cut out and the full supply of current is furnished by the battery, which is large enough for a ten-hour supply at full load.

Storage Batteries for Electrical Laboratories. The great advantage of this source of power in electrical laboratories, is the fact that any variation in the voltage is very gradual, and by the simple regulation of a rheostat in series with the battery, the operator can keep his voltage and current absolutely constant, while a test or calibration is being made. When a large current is wanted, as in the case of ammeter calibration, the cells may be connected in parallel, and discharged through a low resistance, thus cutting down the energy required for the test. A storage battery may also be used to step up the voltage, the cells being connected in parallel groups for charging and in series for discharging.

Connection and Regulation of Storage Batteries. The complete control of a battery in an electric-lighting plant requires provision to be made for feeding the lamps, etc., from either the dynamo or battery separately, or from the two working in parallel; and it should be possible to charge the battery at the same time that lamps are being supplied. To accomplish these results requires three switches,— one to connect the battery to the dynamo, one to connect the lamps to the dynamo and one to connect the lamps to the battery. In some plants the second switch is omitted, because the lamps are always fed by the battery alone, the latter being charged during the day, when no lamps are in use. However, it would seem desirable to have all three switches in every plant in order to be able, at least, to supply lamps and charge the battery at any time. In the battery circuit there should be an amperemeter having a scale on both sides of zero, so that it shows whether the battery is being charged or discharged, as well as the

value of the current. Another amperemeter is required in the circuit between the dynamo and the battery, to show the direction and amount of current. A third amperemeter is desirable in the lamp circuit, to show the total current supplied to the lamps; but it need only indicate on one side of zero, since the current there always flows in the same direction. A voltmeter is required with

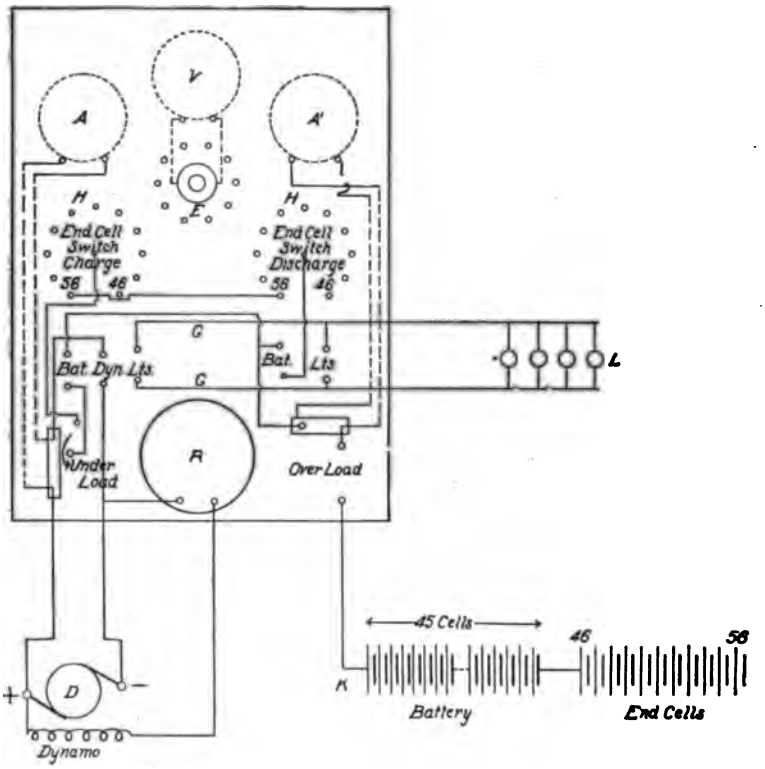

Fig. 24. Switchboard, Dynamo and Battery Connections.

a three-way switch, which enables it to be connected to the dynamo, battery, or lamps respectively.

An automatic overload switch must be inserted in the battery circuit so as to open or introduce resistance into the circuit when the current becomes excessive. An automatic cut-out is required between the dynamo and the battery to open the circuit when the charging current falls below a certain value, and thus avoid any danger of the battery discharging through the dynamo, if from

any cause the E.M.F. of the latter drops below that of the former. This completes the ordinary measuring and circuit-controlling apparatus employed in connection with storage batteries. The arrangement is shown diagrammatically in Fig. 24, in which A and A^1 are the two amperemeters, the third one being omitted in this case; V is the voltmeter; E the voltmeter switch to connect to the dynamo, battery, or lamps as desired; G the bus bars; L, lamps; D, dynamo; R, rheostat in field-circuit of dynamo.

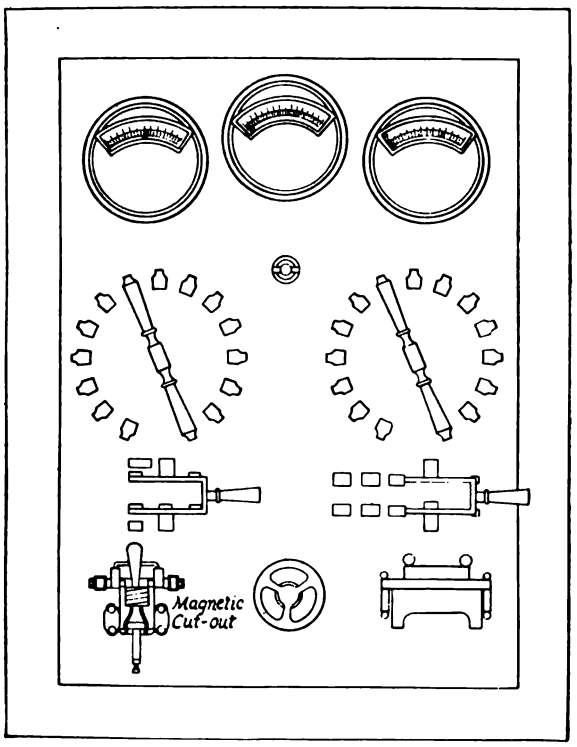

Fig. 25. Face of Switchboard.

The regulating device consists of eleven end cells, which are connected to corresponding contacts on the end cell switches (Fig. 24). But as the drawing of these connections would complicate the figure, they have been omitted. Fig. 25 shows the switchboard with these devices mounted upon it.

The Regulation of Storage Batteries is one of the most

troublesome matters involved in their practical use. This arises from the fact that the voltage falls continually from the beginning to the end of discharge. To be sure, this decline is gradual; but its total value is large, being from about 2.2 to about 1.8 volts, which is a decrease of nearly 18 per cent.

In order to maintain a constant voltage, the usual plan is to have a number of extra cells, which are successively switched into circuit as the potential falls. These reserve cells and the switches which control them are represented in Fig. 24.

The contact pieces of these switches must be made in such a way that they do not short-circuit the cells as they pass from one point to the next. This is accomplished by splitting the movable contact arm into two parts, between which a certain amount of resistance is introduced, so that when the two parts happen to rest on two adjacent contact points, the resistance prevents the cell which is connected to these two points from being short-circuited, and also avoids breaking the circuit.

The number of extra cells depends upon the conditions; for 110 volt lamps, it would require 51 cells to obtain 112.2 volts when fully charged and giving 2.2 volts each, assuming the drop on the conductors at 2 per cent. When the battery becomes discharged, and its potential falls to 1.8 volts per element, 10 additional cells or 61 in all, would be needed. These would yield 111.8 volts, assuming the average potential of the reserve cells to be 2 volts, since they have not been discharged to the same extent as the original battery. If the drop on the conductors is 10 per cent of the lamp voltage, the potential at the battery will have to be $110 + 11 = 121$. This will necessitate 4 more elements, or a total of 65 when the 51 original cells are fully discharged to 1.8 volts, and the 14 extra cells give 2 volts each.

For a three wire system the above figures should, of course, be doubled. This switching of extra cells into and out of the circuit obviously results in discharging them unequally, hence they require to be charged to a corresponding extent. This is accomplished by successively cutting the cells out of circuit as soon as they become fully charged, the last cell which was put into the circuit being fully charged in the shortest time, and so on. The amount of charge is determined by the methods already

given. If the cells employed are not injured by overcharging, they may be left in circuit until the entire battery is fully charged. This saves the trouble of operating the switch; but it is wasteful of energy, since the full counter E. M. F and resistance of the charged cells must be overcome, which requires about 2.5 volts more per element. The switches might be operated automatically by a voltage regulator or by clockwork.

REGULATION OF GENERATOR IN CHARGING STORAGE BATTERIES.

The variation in E. M. F. which occurs in accumulators renders it somewhat difficult to regulate the generators employed to charge them. A constant potential will give a decreasing rate of charge, owing to the gradual rise in counter E. M. F. This is advantageous, in that it enables the cells to receive a larger charge, but the increase in their voltage is so great that it is practically necessary to regulate the charging potential. In practice it is customary to maintain the charging current approximately constant for considerable periods of time, otherwise it would be difficult to determine the quantity of energy put into the battery, and its efficiency. When extra cells are used they facilitate the regulation of the generator, since they are gradually cut out as the E. M. F. rises.

If the lamps are supplied at the same time that the battery is being charged, some provision must be made for the fact that it may be necessary for the voltage of the dynamo to be considerably higher than that required by the lamps. One plan is to have two separate switches connected to the reserve cells, as shown in Fig. 24, the charging current from the dynamo being led in through one, and the current for the lamps passing out through the other, so that the potential can be independently controlled in the two circuits. Another method is to insert counter E. M. F. cells (without active material) in the circuit between the dynamo and the lamps, in order to bring down the voltage of the former to suit the latter. The number of these cells is varied in accordance with the excess of the potential of the dynamo.

Simple resistance coils may be used in place of the counter E. M. F. cells to reduce the pressure; but the cells have the great advantage, that they have an effect practically independent of

variations in the current. All of these methods, however, involve a waste of power, the value of which in watts is the product of the current in amperes, and the number of volts by which the potential is cut down. In small plants this loss is not serious, but in large plants or central stations it may become very considerable.

Booster Methods of Regulation. The best plan is to make use of a "booster;" in which case the main dynamos are run at the proper voltage to supply the lamps directly, and the additional pressure required to charge the battery is furnished by the booster. This is connected in series with the dynamo, being inserted in the circuit between the latter and the battery.

When a battery is placed at the end of a long feeder to compensate for line drop, and at light loads to act as a storage reservoir it is not usual to equip this "floating battery" with any regulating device. In such cases the battery is simply connected across the line, and the charge and discharge are determined by the feeder drop. For instance, when a small load is on the line, the drop is small, and the potential applied across the battery terminals is high enough to send a charging current into the battery, if the load on the line increases the drop naturally increases, the pressure at the end of the line falls, and if it falls below the battery voltage, the battery discharges in parallel with the generator, and carries a certain portion of the load. The "floating battery" has the advantage of simplicity, and acts immediately, as it has no time lag which is always present in any apparatus depending upon changes in magnetization. Usually the variations in voltage and the fluctuations in load are too great for successful operation of a floating battery on any but an electric railway or power circuit, and a booster would be required if incandescent lighting be a part of the load.

The duty of a booster is to vary the voltage at the battery terminals with variation in load, causing charging or discharging of current as conditions may require. The booster is an auxiliary dynamo, the E. M. F. of which is used to raise or lower the voltage in the battery circuit. These machines are classified as series, shunt, compound, differential and constant current boosters.

The Shunt Booster is a shunt dynamo, driven by any source

of power, having its armature circuit in series with the line from generator to battery. This form is used in plants, where the bat-

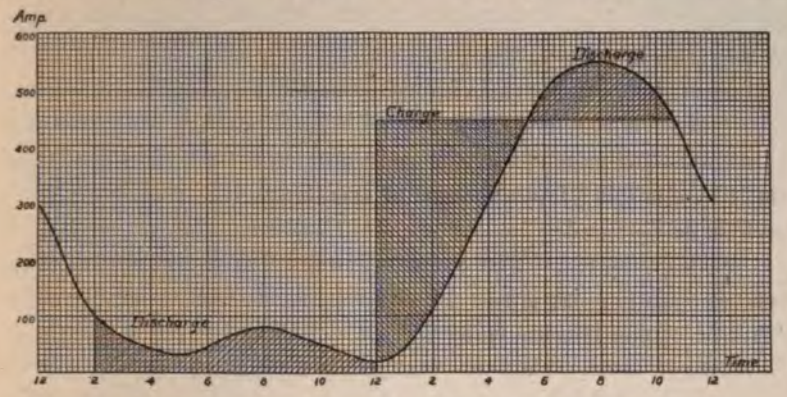

Fig. 26. Load Diagram of Case where Shunt Booster is Applicable.

tery is not designed to take up load fluctuations, but is in service only to carry the peak of the load, being charged during periods of light load, and discharged in parallel with the generator. It acts to increase the voltage applied to the battery so that the

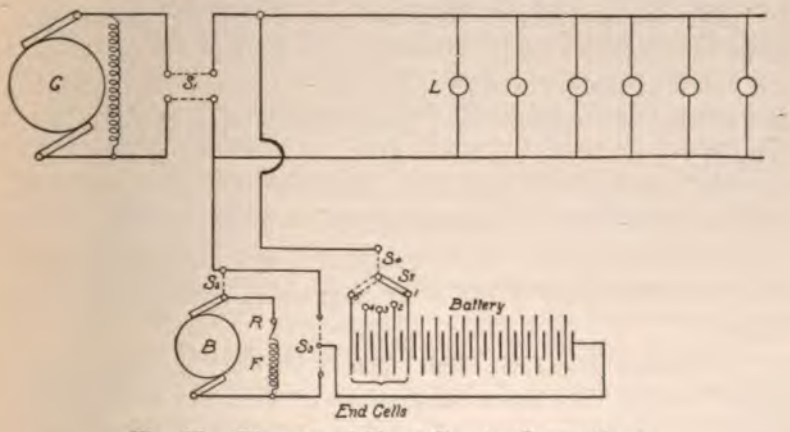

Fig. 27. Diagram of Shunt Booster Connections.

charging current will flow into the latter. As a rule the battery used in conjunction with a shunt booster is made large enough to carry the entire load during the light load period. As the battery discharges and its voltage drops, the "end cells" (regulation cells)

are cut in and the proper voltage maintained. Fig. 26 shows a load diagram to which this system is applicable, and Fig. 27 shows diagramatically the connections of this system. A rheostat is used to vary the booster voltage, so as to hasten the charging of the battery if desired. It is to be noted that the shunt booster is not applicable where there are sudden fluctuations that are great compared with the capacity of the generator, and that it is not automatic in changing from charge to discharge, the switching being performed by hand.

Series Booster. The connections are like those of the shunt booster with the battery and booster in series across the line but the field of the booster being in series with the battery circuit, its E. M. F. is zero when no current is flowing in or out of the battery. Should the voltage of the line rise, due to a decrease of load, and a charging current flow into the battery, the E. M. F. of the booster would increase, and thus tend to increase the rate of charge. The reverse occurs when the battery discharges, as an increase of load on the line increases the current through the series field of the booster, thus raising the voltage of discharge so that the battery carries a larger part of the load.

This booster acts to compound the battery on discharge, and tends to maintain a constant voltage on the line. It depends on the fact that the generator voltage falls when the load increases; hence it is used with a shunt generator or equivalent source of supply.

This system is applicable to power but not to lighting purposes, and is similar in its operation to a "floating battery." It is not as extensively used as the compound and differential booster arrangements which give better regulation under similar conditions.

Compound Booster. This system is used on railway and power curcuits with great fluctuations in load, the battery acting to prevent excessive drop and to assist the generating machinery in carrying the load, relieving it from the strain of sudden rushes of current. The connections of this system are indicated in Fig. 28, and the operation is as follows: — Under normal load conditions the shunt field Fh of the booster creates an E. M. F. in the same direction as the battery, tending to discharge it. Calling E_g the

generator E. M. F. E_a, the booster E. M. F. and E_b the battery E. M. F., we have $E_g - E_a = E$, when no current is flowing into or out of the battery. In this case the generator carries the whole external load.

If the load increases E_g decreases, so that $E_b + E_a$ is greater than E_g, and the battery begins to discharge. In discharging, the current passes through the series field Fs of the booster and produces a proportional E. M. F., acting with the shunt field to raise

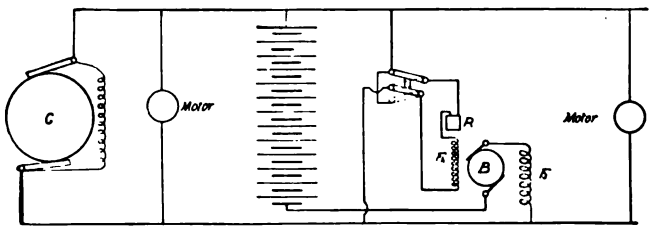

Fig. 28. Diagram of Compound Booster Connections.

E_a, thus increasing the battery discharge and shifting more of the load from the generator, until the system becomes balanced.

If the load on the external circuit be light, the generator voltage E_g rises and current flows into the battery. In this case the series field acts against the shunt field and decreases E_a, so that the generator voltage is greater than booster and battery voltage combined, thus increasing the rate of charge of the battery, until the load causes the generator voltage to drop to normal and the system is again balanced. The battery and booster can be placed at the power house or at the point at which the greatest drop is likely to occur.

A battery can also be used to help out the generators at the peak of the load, by increasing the shunt field current and thus causing $E_a + E_b$ to be greater than E_g.

Since this system also depends for its action upon the drop of voltage with increase of load, it is only applicable to shunt wound generators or equivalent source.

Differential Boosters. The differential booster system most commonly used, is shown in Fig. 29.

The compensating field S_1 prevents the variation of the battery E. M. F. from disturbing the equilibrium of the system. If

the battery E. M. F. be lower than normal it will not discharge rapidly enough to relieve the generator from overload fluctuations, unless the booster E. M. F. be increased, and the generator will therefore have to supply a current of greater than its normal value. If however a current of greater value than the normal flows through S_1, the value of (f–S_1) is decreased, and S_2 still further overpowers the resultant of (f–S_1) and causes a higher booster E. M. F. tending to discharge the battery, and thus brings down the generator load to normal. Should the battery E. M. F. be above

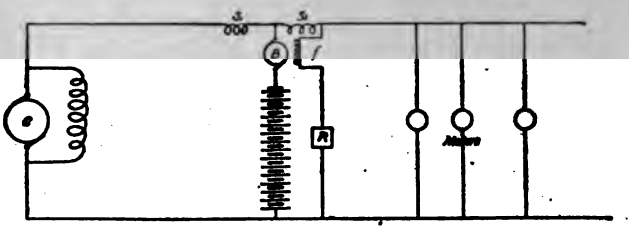

Fig. 29. Diagram of Differential Booster Connections.

its normal value, the battery would discharge too rapidly and carry more than its share of the load; in this case (f–S_1) is greater than it should be, and the booster E. M. F. causes the load to become evenly distributed between the battery and generator.

In operating this system the varying load must be beyond the booster equipment. If desired the coils S_1 and S_2 may be short circuited so that the battery may be charged more rapidly.

Constant Current Booster. In systems having short lines and small drop it is often desirable to have the voltage fall on sudden application of an overload, so that the rush of excessive current is prevented. This rush of current occurs in buildings where elevator and power motors constitute a large percentage of the load, and to prevent it, the constant current booster system is used.

Fig. 30 represents a constant current booster system, in which the main current passes through the armature and series field of the booster, and this current does not reverse.

The voltage impressed on a fluctuating load of motors on the right, is greater than that impressed on a non-fluctuating load of lamps on the left, by the amount of the booster voltage.

The shunt coil f creates an E. M. F. in the same direction as the generator E. M. F., while the series coil F opposes it.

Should a load come in the motor portion of the circuit, the generator sends a greater current through the series coil S, the action of which reduces the booster E. M. F. in direct proportion to this rush of current, and causes the booster E. M. F. to vary inversely as the motor load, thus tending to maintain an almost constant current delivery from generator. If it is desired to have

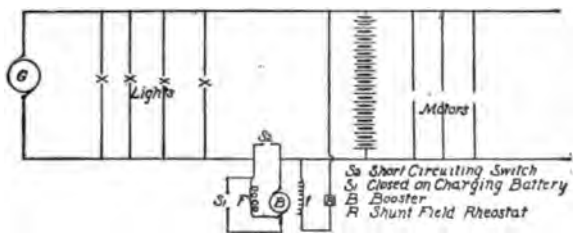

Fig. 30. Diagram of Constant Current Booster Connections.

the battery furnish power to both the lights and motors, at periods of light load, and not use the generator, this can be done by simply opening generator switch and short circuiting the booster by closing switch S_2.

The switch S_1 is closed in charging the battery, as the rate of charge can be controlled by varying the shunt field resistance R. This is often done, when the battery has been carrying a heavy load for some time and the recharging must be hurried.

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USE OF THE AUTOMOBILE IN WAR.—AUTO-TELEGRAPH CAR OF THE SIGNAL CORPS, U. S. ARMY.

A Scene during the Manœuvers of 1904 on the Historic Battlefield of Bull Run.

AUTOMOBILES

As a device for saving time and distance, the motor vehicle bids fair to eclipse all others and to prove itself one of the greatest inventions of an inventive age. Its motor will, in time, be built cheaper than a horse can be grown, its transmission gear will cost less than a harness, while its body need cost little, if any more than similar parts of horse vehicles. Rapid as has been the growth, and astonishing as are the results shown to-day by this class of vehicles, it is evident that this is but the beginning and that in the very near future, a development and growth far beyond present conception is sure to come.

The motor vehicle is not a new invention. It is the father of the traction engine and of the locomotive. It is one of the devices earliest sought for but latest to be practically and popularly worked out; and few problems of greater severity have been presented to engineers. Its need has been felt everywhere, for we spend our lives exchanging what we have for what we desire and this requires transportation. At both ends and often between ends of the route over which the exchange is made animal power is used and here the auto is needed and will be used with great saving. The director of the United States Road Inquiry Bureau says the cost of moving tonnage 1250 miles by steamships, 250 miles by steam cars, or 25 miles by electric cars is no greater than the cost of moving tonnage 5 miles by animal power on the common roads—a proportion of 1 to 5, 1 to 50 and 1 to 250 in favor of mechanical transportation against the horse; and yet with these figures before them, capitalists build larger steamships and better railways in an attempt to save an additional slight percentage on these already cheap methods, while the horse has continued to draw the same old wagon at a snail's pace over abominable roads, simply because heretofore the motor vehicle has not come into use.

On the other hand while this has been the general condition, there have always been attempts to secure better results. Pioneers have exerted themselves to build mechanical motors for use on the common

roads in the face of the great chances of failure and the derision of the world. To them we owe the progress that has been made.

HISTORY

Nearly three centuries ago a German at Nuremberg proposed to drive vehicles "2000 paces an hour by means of springs," and similar carriages were proposed by others. In 1759 Dr. Robinson called the attention of Watt to the possibilities of steam vehicles. In 1763 to 1769 Cugnot, a Frenchman, designed and built with the assistance of the French War Department, a steam-propelled gun-carriage and in 1797 a four-passenger tricycle capable of four miles per hour. In England a practical result was shown in 1781 by Murdock and in America by Oliver Evans in 1804. These were mostly steam vehicles, although gunpowder engines much resembling gas engines were among the earliest proposed. Compressed air was also used, notably by Mann in 1822 and others.

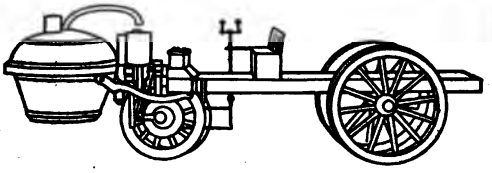


Fig. 1. Cugnot's Steam Carriage, 1769.

The first half of the 19th century was marked by many attempts at motor road-locomotion and many vehicles, particularly omnibuses for public hire, were made and operated between 1820 and 1844 by Hancock, Gurney, Church, Fisher, James, Squire, Russell (constructor of the Great Eastern Steamship) and others. These vehicles were operated with success on regular schedules over regular routes, were much liked by travelers and were crowded with passengers, and they bade fair to inaugurate the horseless age and bring in an era of cheap transportation.

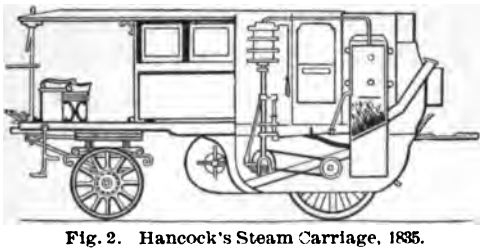


Fig. 2. Hancock's Steam Carriage, 1835.

Public opinion, however, was not with these vehicles. Horse users and stage drivers were very bitter against them. The Road

Trustees imposed unjust and discriminating tolls and the ill feeling and prejudice finally resulted in restrictive laws prohibiting a speed faster than three or four miles per hour and compelling a man to precede the vehicle with a red flag. The result was that the industry died and did not again exist in England until the passage of the "Light Locomotives Act" in 1896, a loss of more than 50 years and of millions of dollars that would otherwise have gone to the English nation. In the meantime the locomotive was developed to run on special rights of way and the traction engine plodded at a snail's pace whenever it used the highways.

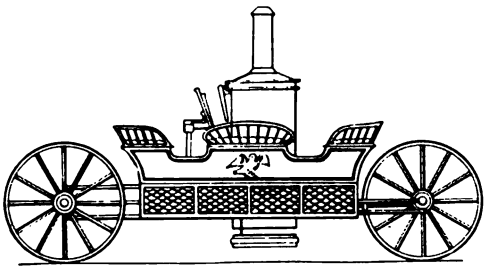


Fig. 3. Fisher's Steam Carriage, 1840.

Occasional Experiments. Occasional inventors made experiments from time to time in France, Germany and America, but for one reason or another none of these found favor. In 1860 to '62 Lenoir, a Frenchman, designed a gas engine of the four stroke cycle type and applied it to a motor vehicle. Ten years later the elder Bollee built one or more steam vehicles which received some use on French roads. About 1876 Fawcett, at Pittsburg, built an omnibus using a Brayton internally fired engine burning liquid fuel. Ten years later Copeland in America fitted small, light steam motors to bicycles and tricycles with some degree of success, while Daimler and Benz in Germany about the same time applied gas engines of the four cycle type successfully to motor vehicles.

The next ten years marks the beginning of the present motor vehicle industry. In Germany, Daimler developed the small high speed motor which is admittedly the predecessor of present day practice. Benz, his countryman, confined himself more to the application of engines resembling stationary engines, and while very successful, so far as quantity of vehicles made and service rendered is considered, did not influence the industry as did Daimler whose inventions were taken up in France about 1892 or '93. In America, occasionally experimenting since 1886, the Duryea Bros. began continuous work

on gasolene vehicles in 1891, which work unlike many experiments, has been carried forth continually since. In 1893 Sturgess, of Chicago, exhibited an electric vehicle at the Columbian Exposition.

In 1894 and 1895 very successful road contests were held in France and attracted the attention of the civilized world. These were followed by several automobile events in America, the first of which was the Times-Herald contest at Chicago.

Fig. 4. Five Horse-Power Runabout, 1896 Model.

Pioneers. It is difficult in a historical account, to set a proper value on the various experiments and attempts made in different parts of the world, for no one can say what bearing or influence any particular experiment may have had on the work of later builders. It is eminently proper, however, to give credit to work that has continued with little or no interruption into the present period; to work that showed marked pre-eminence either by the results accomplished or by the means and mechanism used, and to work that has in any way stamped itself upon present practice to a noticeable extent. Judged by these standards the pioneers in the electric vehicle field were Sturgess, 1893, Morris & Salom, 1894 and '95, Woods, 1895 and Riker, 1896. In steam vehicles the work of Copeland (given considerable prominence through the Cycle publications), was followed about 1896 and '97 by the successful steam carriage of Whitney, which was the direct predecessor of the product of the Stanley Bros., first introduced to the public at Charles River park, Boston, Mass., in the fall of 1898. In gasolene vehicles, the

Fig. 5. Two and One-Half Horse-Power Phaeton, 1902 Model.

first Duryea finished in 1892, and the second one finished in 1893, both of the single cylinder variety, were followed in 1894 by the double cylinder carriage which won the Chicago Times-Herald contest. The first single cylinder Haynes vehicle was finished in the summer of 1894, followed late in 1895 by the second Haynes, a two cylinder vehicle, the first of the opposed cylinder type. In 1896 the first Winton made its appearance, while in this same year more than a dozen Duryea vehicles were completed and the new industry was fairly started on its way.

Little Interest. Progress was at first slow both in America and England, although more rapid in Germany and France, due to the favorable roads, liberal laws and greater interest among experimenters and capitalists. In America, the downfall of the bicycle business destroyed much of the financial confidence necessary to the development of the new industry and interest lagged until the steam vehicle shown by the Stanleys in 1898, and offered to the public by many makers at a low price, began to be put on the market in a large way and extensively advertised. It met with an enthusiastic reception, was not protected by patents and was therefore largely copied by other makers, with the result that it seemed to have the field to itself. The steam vehicle, as then constructed, however, fell from popularity, even more rapidly than it attained it. The great complexity, the delicacy of the many parts, the small wheels, the inadequate tires, the short wheel base, together with many other features of similar character, all contributed to the downfall of this promising, popular carriage.

In the meantime, the electric vehicle was being exploited by large capitalists in the large cities for public service, and cab companies, overcapitalized, sprang up in many places, doomed to disappointment because of the lack of experience and the fact that their vehicles had not been proved by years of service to be what was needed for their work. This adverse experience did much toward holding back the adoption of the electric vehicle by many to whom it would have been of great value, and hurt the business generally.

Steady Growth. Across the ocean Serpollet, beginning about 1886, had been slowly developing a promising steam vehicle while one or more experimenters were developing the electric. The gasolene vehicle, pushed by many, made most rapid progress. In America also, it made progress conservatively but steadily. Fathered by mechanics,

rather than by capitalists and promoters, it was steadily improved, its defects and limitations were studied, it was sold at a price consistent with good quality, and although slow in coming to its recognition, the certainty of that recognition was made more sure by the very length of the period devoted to its development.

This slow growth gave opportunity for experimentation and brought into existence most of the valuable features of present day autos as well as some features that will undoubtedly be used in future years, although not recognized at their true value now. Thus the first Duryea vehicles, finished in 1892 and 1893, had front axles fitted with wheel pivots or steering heads as close to the wheels as possible, and these pivots were inclined, so as to strike the ground at the bottom at the point of contact of the wheel, which arrangement secures a steering that is practically irreversible, that steers very easily and permits running over obstructions with no shock on the steering parts or tendency to deviate from a straight line—facts which are not yet fully known by constructors and therefore not made use of to a large degree. They employed a three point rear frame with motor and transmission mounted closely together upon it, double side-chain drive with balance gear in the counter shaft, electric ignition, spray carburettor, motor lengthwise the body and many other devices that have since become standard practice.

This period of the history of the gasolene vehicle was not influenced by foreign practice and was more truly American and better suited to the American roads and conditions than many present-day constructions, although at that time the full importance of ample power was not recognized, mechanics were untrained, and many vehicles were incapable and unreliable.

Steam Decadence. About the time of the decadence of the steam vehicle fad, 1901, two vehicles of particular importance began to attract attention,—the Olds and the Knox. The Olds is interesting because of the distinctive shape of the body which resembled a toboggan at its forward end, the shape of the springs, which were fastened at one end to the body and at the other to the axles, and the generally light and simple appearance. This vehicle was put out in large numbers at a moderate price, was quite successfully imitated by many other concerns, and was for a time the representative American type, and recognized as such in many parts of the world. The Knox equally

deserves mention because of its system of air cooling, which was really the only successful form for a considerable period. Many attempts had been made at air cooling, but most of them had been failures for one reason or another; but Knox, by his firm belief in the efficiency of threaded pins screwed into the walls of the cylinder, including the head and valve chambers, demonstrated the practicability of this system, and although standing alone, after others had abandoned air cooling, for all except the smallest sizes, has been followed by a great variety of very efficient air cooling methods.

Fig. 6. Standard Oldsmobile Runabout.

Foreign Influence. Abroad, the gasolene vehicle was turned out in large numbers, and was seen, tried, admired, and purchased by the vast number of American tourists, who, too busy at home to even look at an auto, became willing converts abroad and spent their vacations enjoying the good roads of Europe and the new method of locomotion at the same time. The earliest vehicles of Daimler had been fitted with a motor under the seat, but in order to secure greater accessibility he soon transferred this to the front of the vehicle, where it was enclosed in a box, and this practice has prevailed abroad to the present day and has been followed very largely in America through the influence of the tourists.

The splendid foreign roads with their hard surfaces and easy

grades permitted the use of small wheels, of mechanism close to the ground and required so little traction that no great weight was needed upon the driving wheels; while favorable speed laws and road conditions permitted the use of high powers and the attainment of railroad speeds.

American Conditions. In America, where the majority of the roads are bad, the things demanded of a motor vehicle are considerably different, and they are not properly met by foreign designs so prevalent to-day. Rough roads require large wheels, ample clearance under the body, protection of the mechanism from mud and dust, great weight on the propelling wheels, large wheels that will roll over rough places easily, a simple and light mechanism that will stand the rough service with the minimum of repairs. Many other similar features are essential to meet the road conditions and also the needs of a thoroughly practical people, rather than those designed simply to serve as a sport of a leisure class. It seems evident, therefore, that many of the features first developed in America, to meet American conditions, and more or less largely abandoned in favor of foreign design, will eventually become standard American practice, because best suited to American needs. Fluctuations are, of course, apparent in the development of any new industry, for, in their inexperience, the buying public is apt to grasp at new designs as the solution of its difficulties, without really knowing whether the new is better or as good as the old, but as a wider variety of styles is seen in use, these fluctuations will become less pronounced until finally purchasers will have a large variety from which to select and particular needs rather than present fad will more largely influence the selection.

Present Types. Present-day autos can be divided into a wide number of classes in addition to the three general classes, electric, steam and gasolene, already considered. In electric vehicles, there is but little variation except in the shapes of the body, although some vehicles are equipped with two motors, others with but one, and batteries vary somewhat in arrangement, kind, and size, while controllers and fittings exhibit the designers' preferences.

The electric vehicle is of limited range and well adapted to city use for elderly people or ladies. Like the steamer, it seldom needs attention on the road and generally gets home if the batteries are not exhausted. The batteries, like the steam boiler, are the objectionable

feature, for they are quite complicated, heavy, subject to chemical change; also to physical change, such as buckling, loosening of the active matter from the plates and leakage, spilling or evaporation of the electrolyte. The density of the electrolyte needs watching to secure best results, and the batteries should always be kept charged.

Steam Vehicles. These are considered well-known because they employ steam engines and boilers and do not ordinarily use a speed changing device. The White steamer uses a tubular generator in which the water enters the top and is converted into superheated steam by contact with the hot metal. No water is carried in the boiler,

Fig. 7. White Tubular Generator.

so little time is required to get up steam, and an increased supply of water is met by an increased fuel supply, resulting in increased quantity of steam. With the steam vehicle, pressure is required to make the fuel mix with air, and the burner requires more or less attention. The piping, pumps and stuffing boxes must be known to be in good order, and loss of power is usually attributed to a leak or to improper fuel and water supply.

In the Stanley steamer, the motor is geared direct to the rear axle, instead of being connected by chain as in most other forms. The light weight of the Stanley steamer, and also the Baker electric vehicle contribute much to the high efficiency shown by these light carriages.

Steam vehicles differ principally in the type of boiler, there being two general kinds, the fire tube, of which the Stanley is best known, and the flash or generator, of which the White is the principal exponent. Burners, engines and their arrangement vary also.

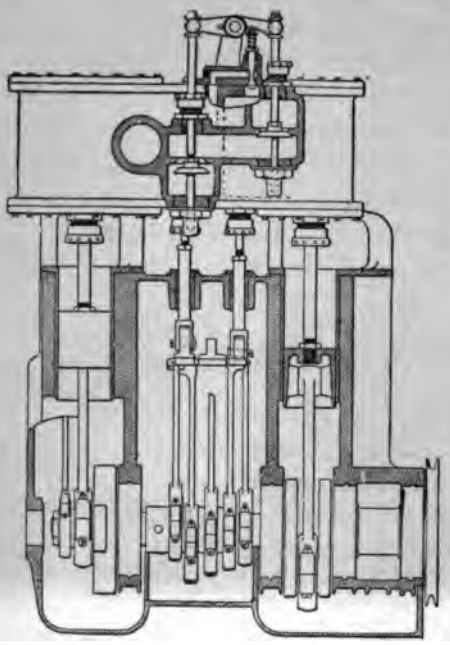


Fig. 8. Diagram of White Steam Engine.

Variations. Since, however, the majority of present day autos are gasolene vehicles, it will suffice to describe in them, most of the details that enter the auto of to-day. Besides the variations in the body, such as single or double seat, folding seat or detachable, open, with top or enclosed, side or rear entrance and many similar variations, there are two kinds of motors, two-stroke cycle and four-stroke cycle; two varieties of cooling, air and water; three locations of the mechanism, front, midway and rear; several forms of transmission, such as belt, friction, chain, planetary gear, sliding gear, individual clutch, and many variations including combinations of hydraulic and electric systems. There are two largely-used methods of ignition, with several accepted sources of electric current, viz., the jump and the contact spark; with primary batteries, storage batteries, magnetos and dynamos for supplying the electricity. Since, however, there are several hundred parts required to make up a motor vehicle, it seems best to describe these parts under various headings rather than attempt a general description which cannot be other than confusing.

The motor vehicle is commonly considered as a combination of a motor and vehicle with such other parts as are needed to make the combination operative, and in this connection the motor is described first. Since, however, vehicle motors are but modifications—usually

light and of high speed—of motors long used for stationary work, it will not be necessary to include here so complete a description as would otherwise be the case, since this information can be obtained in text books treating directly of the motor.

THE MOTOR

The theory of the gasolene motor is that a mixture of air and gasolene vapor is drawn into the cylinder of an engine and ignited, after which the pressure, due to the expansion, is caused to perform work in propelling the vehicle. The essential parts are the *cylinder*,

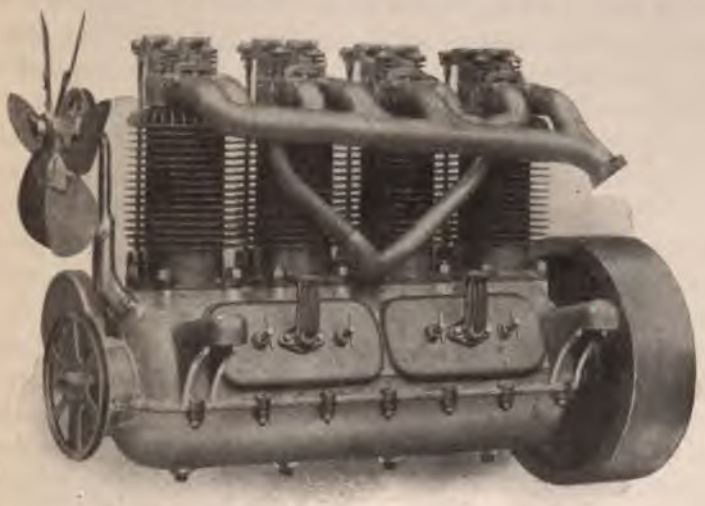


Fig.9. Four-Cylinder Gasolene Engine.

piston, *crank shaft*, *fly wheel*, *inlet* and *exhaust* devices, *ignition* arrangement, *vaporizer*, and means of *control*, together with important incidentals, such as lubrication and means for cooling..

Cylinder. The cylinder of the engine for auto use is usually from three to six inches bore, with stroke sometimes longer, sometimes shorter, but quite generally the same as the bore. Cast iron is the usual material from which the cylinders are made, and provision for cooling, such as a water jacket, is usually cast integral with the cylinder, although quite frequently affixed in the form of a sheet metal jacket on pins after the cylinder is machined. These cylinders may be attached to

the crank case or formed with part or all of the crank case in one piece. Each method of construction has its followers and each has its advantages, according to the design of motor, crank shaft and similar parts. In motors of the type first used on DeDion tricycles, the flywheels were disks enclosed in the crank case and forming the crank sides, and since they practically filled the crank case, it was necessary that this be made in separable halves. The separation was in the plane of the crank rotation, which permitted each half of the case with its long, hardened and lapped but nonadjustable bearing, to be removed by sliding off opposite ends of the crank shaft. The cylinder was held to this case after the halves had been brought together, by screws or bolts. In many instances the head of the cylinder was held against the cylinder end by the same bolts, so that the cylinder was actually clamped between the head and the case. This design employed a cylinder open at each end, making a quite simple casting and facilitating machining.

Other cylinders are built with a simple head screwed in position, and with the ports on the sides of the cylinder instead of forming part of the head. Air-cooled cylinders are most frequently provided with circular flanges spaced one to three times their thickness apart, and rising above the cylinder wall from two to ten times their own thickness. In some cases these flanges are of sheet metal of great conductivity, as copper, forced tightly upon the smooth wall of the cylinder, or they are of smaller pieces attached by calking, clamping or other effective form of contact in or to the cylinder wall. It is essential for good results, that the cylinder should be true, particularly when hot, for if it is not truly round, and practically parallel throughout its length, the piston rings will not fit, and will not retain the gases which, leaking past the piston, leave their heat in the cylinder walls, blow away and burn up the lubricating oil, and cause excessive heating, pounding, loss of power, premature ignition and even cutting of the metal surfaces, destroying both piston and cylinder.

Valve Ports. The most common arrangement of the ports employs a pocket or passage at one side of the cylinder head in which the valves and frequently the sparking parts are placed. The exhaust valve is the nearest the crank shaft, with its stem extending toward the crank shaft where it is conveniently operated upon by the cam on the half time shaft which lifts the valve every second revolution,

as is required in a four cycle engine. The inlet valve is placed with its stem in the same axial line but projecting in the opposite direction, and is held closed by a spring and opens by the suction of the piston. By this arrangement the cool incoming charge strikes the exhaust valve and sparker parts and much reduces the temperature. Burnt gases are carried out of the pocket, leaving a fresh combustible mixture therein which contributes to certain ignition.

Recent designs have employed double cam shafts on opposite sides of the motor with valve pockets likewise on opposite sides, the inlet valve being mechanically opened, and arranged the same as the exhaust valve. These double pockets increase the wall of the compression space and therefore the loss of heat, and lessen the economy.

To avoid this increased wall surface of the compression space, many constructors now place the valves in the head of the cylinder with their stems projecting away from the crank shaft, and operate the valve by rocker arms, or place the cam shaft beyond the cylinder head and drive it by chain and sprockets instead of gears.

Whatever the form of cylinder and fittings, it is essential that there be good compression, or, in other words, that the contents of the cylinder be not allowed to escape. To test the compression, turn the engine by hand until the piston comes against the contained gases as against a strong spring, and judge by the length of time that this resistance continues as to the rapidity of the escape. A tight cylinder properly lubricated ought to resist a pull on the starting crank for a minute or more and should require considerable effort to force the engine past the compression. The operator should distinguish between high compression and good compression. If the clearance at the head of the cylinder on the compression dead center is small, the engine is known as "high compression" and if turned quickly, the resistance will be high, even though the valves or piston rings may be leaking and the compression therefore not good.

Faulty Compression. If the compression is faulty the escaping gas can usually be heard, announcing its escape by hissing. The point of escape must then be found and will usually be at the exhaust valve, for the inlet valve, being kept cool by the incoming charge, seldom needs attention. If the passages can be opened, a candle flame will, by its flickering, indicate the leak, to remedy which the valve must be removed and ground. Grinding a valve consists in oscillating it upon

its seat until the high spots are worn down, so that the valve bears equally and fully all around, thus making a tight joint. Flour emery mixed with oil is usually used, but a tighter and smoother job may be secured by finishing with powdered glass or sharp sand like the powder from the water-trough of a common grindstone.

If the leak is around the piston rings, new rings or newly fitted pistons may be needed. To avoid damage to the piston or cylinder, the operator should stop immediately if the engine begins to pound, smoke, or lose power, and he should determine the cause of the trouble before proceeding. Lack of water, a broken belt on the cooling fan, or lack of oil will usually be found causing the trouble.

Piston. The piston is the moving part which fits into the cylinder and against which the explosive pressure is exerted by the burning gases. Pistons are usually from one to two times their own diameter

Fig. 10. Pistons and their Connections with Crank Shaft.

in length and are provided with two to four rings at the head and and occasionally with one ring at their open end. They are unlike steam engine pistons in that the pressure is taken on the head end only and that they serve as cross heads, having the connecting rods attached to wrist pins fitted generally about midway the length of the piston. This wrist pin ordinarily passes through the piston walls, lugs or enlargements being provided interiorly therefor. The wrist pin is usually fixed in the piston and the end of the connecting rod has a bearing thereon, although in some cases the pin is fixed in the end of a rod and takes its bearing in the piston, by which means a larger bearing surface is secured, and removable bushings are fitted in from the out-

side of the piston, as in Rambler autos. The head of the piston is quite commonly flat, but is frequently concave as in the Duryea, or convex as in the Autocar, and these forms are stronger and lighter than the flat head. The interior of the head is sometimes provided with radiating webs or pins as in the Frayer-Miller. The piston rings are usually of cast iron machined to a diameter larger than the diameter of the piston and then cut so as to be compressed to the cylinder diameter, which leaves them with a tendency to open and causes them to fit closely to the cylinder wall. They should be fitted carefully to their grooves in the piston, and it is particularly important that their sides be carefully fitted to the sides of the groove, so as to make a gas tight joint and prevent the escape of the gas under the ring. Two rings are often fitted in a single groove with their joints in different positions, and a third ring is sometimes placed underneath, which also serves to close the joint. Various joints are used, but a plain cut of 45 degrees or two perpendicular cuts from opposite sides, each cut being on opposite sides of a dividing line, are sometimes used, making a lap joint that is regarded as superior to the diagonal joint. Care should be taken in removing and replacing piston rings not to spring them harshly, for they will seldom return to their original shape if much abused, and if they do not fit the cylinder they will not serve their purpose properly.

Connecting Rods. The connecting rod attaches the piston to the crank shaft, and since auto engines are desired to be compact, these rods are $1\frac{1}{2}$ to 3 times the piston throw. They are generally of I-beam section, so as to resist the alternating stresses to which they are exposed, but are frequently of U-section, particularly in horizontal engines, so that they may catch oil and direct it into the bearings and thus assist in efficient lubrication. Connecting rods are usually made of forged steel, but steel castings and bronze castings are sometimes used. The wrist end is very frequently solid and fitted with a bushing for the wrist pin, but in many forms this end is provided with a lug at one side, split and drawn together for adjustment by a screw. Occasionally a removable cap is fitted. At the crank end the removable cap is the more common construction. Sometimes this cap is hinged at one side and

Fig. 11. Connecting Rod.

adjusted by a single screw at the other. Bushings of Babbitt metal are very commonly fitted at the crank end.

Crank Shaft. The crank shaft is usually of a high grade steel and is frequently hardened and ground. Bearings are provided at short distances apart, frequently between all cylinders, and seldom if ever farther apart than is required to bring two cylinders as close together as possible. This large amount of bearing surface contributes to long life, and also supports the crank and thus prevents danger of damaging the bearings by strains or damaging the shaft. A wide variety in shafts is found, depending upon the type of engine, the number of cylinders, the class of bearings, and the objects of the designer. Where ball bearings of the nonadjustable type are used, the crank

Fig. 12. Crank Shaft.

shafts have been built up in short pieces, so as to permit putting the ball bearings into position, but this method is not very common. Shafts are frequently made hollow, both in the shaft proper and in the crank pin, for by so doing nearly one fourth the weight can be saved, with little decrease in strength.

The common method of attaching the fly-wheel to auto crank shafts is by means of a flange integral with the crank instead of keyed on, as in most other engine practice. The web of the fly-wheel is bolted to this flange by an ample number of bolts to hold it securely and yet permit easy removal. The saving in space lengthwise of the crank shaft makes this method of particular value in a vehicle like the Duryea, where the width of the body limits the length of the shaft available for the engine and transmission gear, particularly in connection with multiple-cylinder engines. The crank shaft is usually provided at one end with ratchets for starting purposes, with a gear for driving the cam shaft and any other fittings such as pump or magneto, while at the other end the fly-wheel and the connections for the transmission gear are placed.

In some cases the fly-wheel is on the end of the crank shaft opposite the transmission gear, but this is not considered the best practice, because, in suddenly setting a clutch, the inertia of the fly-wheel is transmitted through the shaft to the transmission gear, causing a more or less severe strain on the shaft and requiring a stronger shaft than would otherwise be necessary. In two-cylinder engines it is customary to set the two cranks of the shaft opposite each other, or 180° apart. Other arrangements have been used but have not been found so satisfactory as this. In three-cylinder engines, the cranks are 120° apart and in four-cylinder engines they are 180° apart or the same as if two two-cylinder cranks had been joined end to end with the two outer pistons moving together and the two inner ones together. For six-cylinder engines the setting is the same as if two three-cylinders had been joined—the inner, intermediate and outer pistons respectively moving together. Three bearings for a four-throw shaft and four bearings for a six-throw is quite common practice, as is also five and seven bearings respectively. A few engines have cylinders which revolve around a stationary crank shaft, and in these a single throw shaft is usually used, the Adams-Farwell having five connecting rods attached to the single crank pin. When the engine "knocks" at speed, whether hot or cold, a loose connecting rod or loose fly-wheel should be looked for, lest the shaft be broken by the constantly repeated blows.

Fig. 13. Gasolene Engine with Revolving Cylinders.

Fly-Wheel. The fly-wheel of a gas engine is a sort of necessary evil. Since in a four-cycle engine there are three idle piston strokes to one working stroke, a fly-wheel is necessary to store up the energy of the one working stroke and carry the engine steadily through the three idle strokes. In a single-cylinder engine this fly-wheel must be of considerable size, weighing when used with a cylinder of $4\frac{1}{2}$ x $4\frac{1}{2}$ inches, 150 to 200 pounds. With two cylinders there are double the

number of explosions and consequently only one idle stroke between the working strokes, so the fly-wheel can be reduced in weight nearly one half. With three cylinders the working strokes follow each other with but one sixth of a revolution intermission and a 55-pound fly-wheel, as used on the Duryea, after a long experience with a variety of weights, serves nicely. A three-cylinder engine may be run without any fly-wheel whatever, but this is not considered practical, although a 25-pound fly-wheel, 18 inches in diameter, serves quite well in a 12 H. P. engine, for all except very slow speeds, at which the separation of impulses becomes so pronounced that is is disagreeable.

In order that the weight may be as little as possible, the fly-wheel is made of the largest practicable diameter and the weight is kept as fully in the rim as may be. In many cases the interior surface of the fly-wheel rim is used to form the clutch surface, while the magneto pulley or pump pulley is driven by friction against the outer surface, which in some cases also serves as the driving face for a fan belt. The spokes are screw-propeller shaped in some instances, to throw air for cooling. In others the face of the wheel is a plane and is used for a friction disc, with the edge of another disc bearing against it, and shiftable to vary the speed of the driven disc.

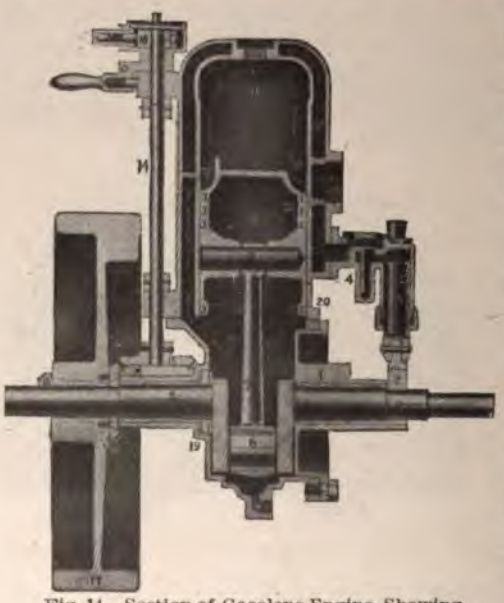


Fig. 14. Section of Gasolene Engine, Showing Enclosed Crank.

Crank Case. In a two-cycle engine the crank shaft is usually enclosed in a tight case arranged to hold pressure to the amount of 5 or 10 pounds under running conditions, although strong enough to hold an explosion which may sometimes occur in the crank case. The cylinder is provided with ports uncovered by the piston at one end of

the stroke, which serve to exhaust the burnt charge and admit the new charge from the crank case into the cylinder proper. Most two-cycle engines are further provided with an inlet port uncovered at the opposite end of the stroke to admit a new charge from the vaporizer into the crank case, where it is compressed by the return, ready to pass into the working end of the cylinder on the opening of the transfer port. Some two-cycle engines have valves, usually of the poppet type, to pass the unburned gases, but these are generally automatic and do not add much complication.

In the four-cycle engine, the cylinders serve the double purpose of containing the working charge during one revolution of the shaft, and the new charge during the next revolution, thus avoiding the use of the crank case as a charge-containing chamber, but requiring two revolutions instead of one per explosion as in the two-cycle engine.

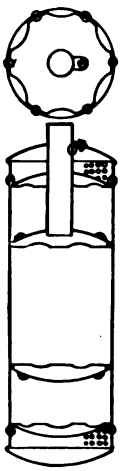


Fig. 15. Diagram of Valve Action.

Valve Action. To accomplish this result with a single cylinder, valves are used both for inlet and exhaust, which are operated ordinarily by a half-time shaft fitted with cams arranged to open their respective valves during substantially one stroke of the four strokes forming the cycle. The exhaust valve is opened about 20 to 25 degrees ahead of the crank shaft dead center, and closed at the opposite dead center one stroke later. The inlet valve immediately opens, and it closes at the end of the next stroke one revolution after the exhaust valve opens. Both valves remain closed during the compression and working strokes.

These valves are variously placed according to the ideas of the designer. A common arrangement places them in the head of the engine with stems projecting from the crank shaft, in which position they are usually opened by rocker arms and plungers actuated by cams on the half-time shaft located in the crank case. In a great number of instances the cylinder or cylinder head is provided with a port passage or pocket on one side of the cylinder head and the exhaust valve is seated therein with its stem projecting toward the crank shaft. The inlet valve may be similarly seated in a similar pocket, or in the same pocket with the stem projecting in the opposite direction. An

advantage of having the inlet valve in the same pocket is that the incoming charge cools the exhaust valve and also the sparking parts, which are frequently located in the same pocket entering through the side thereof, or as in the Duryea, through the exhaust valve stem. It is evident that one pocket requires less cylinder wall than two and therefore loses less heat to the cooling system.

The size of the valves depends much upon the speed required and should be quite large if a high speed is desired. Very satisfactory practical results are obtained by making the exhaust valve one third the piston diameter and the inlet valve one fourth, although to save variety of parts, some designers use the same size valves in both instances, but do not lift the inlet valve so high. Variable lift valves are much in favor because this prevents unnecessary valve movement with consequent wear and noise. In some cases this variable lift is secured by introducing a wedge between two parts of the lifting mechanism, and in other cases by holding the valve against more than a limited lift in response to the suction of the piston, as in the variable lift inlet valves of the Duryea.

Auxiliary Exhaust. In order to get rid of the excess heat, and relieve the regular exhaust valve of part of its duty, some engines are provided with an auxiliary exhaust, consisting of a port through the cylinder wall uncovered by the piston at the end of the working stroke, as in the Fredonia and Franklin machines. It is considered advisable to provide this port with a check valve to prevent back pressure from the muffler from re-entering and lessening or possibly igniting the new charge; although this is probably not so necessary in single or double cylinder engines. Many designers consider the auxiliary valve as an unnecessary complication, used only where the regular valve is inadequate.

Muffler. Connected with the exhaust opening by piping of convenient length, is the muffler, consisting usually of several chambers generally cylindrical, and having walls of sheet iron. This device has usually several times the capacity of the cylinders, which permits the exhaust gases to expand considerably and exposes them to the cool walls, thus reducing their volume by cooling, so that as they escape to the atmosphere they make much less noise than if permitted to escape without the intervention of the muffler. Multiple passages as well as multiple chambers are usually provided, and the silencing

effect seems to be largely derived from interference of the sound waves and gaseous impulses.

Most mufflers offer some back pressure, but if of sufficient size, and provided with three to six chambers, the exhaust of the ordinary auto engine can be silenced as effectually as other noises about the vehicle, with so little back pressure as to not be perceptible in the propulsion of the vehicle if a cut-out is used. Mufflers sometimes clog with soot and dust and do not permit free escape of the gases, particularly at high speed. The large part of the burnt charge remains in the cylinder and prevents the entrance of a new charge, with consequent failure to produce power. Muffler explosions are due to missed fires in the cylinders, which allow the unburned charge to pass to the muffler, where it is ignited by the next exhaust and explodes quite noisily, and sometimes to the damage of the muffler. Muffler cut-outs are often used on hills or where great power is needed, and they avoid any back pressure from the muffler.

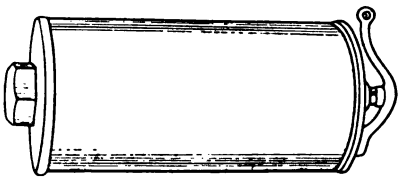


Fig. 16. Muffler and Cut-Out.

Vaporizers. Connected to the inlet ports is the device for mixing the liquid fuel, commonly gasolene, with the proper proportion of air to make an explosive mixture. Formerly this was done by a device for passing the air through the liquid contained in the tank, termed a carburettor, and while good results were obtained therefrom, it was more delicate and not so satisfactory to adjust for varying weather conditions as the devices now used. Present-day devices are modifications of the well-known atomizer used for perfume and medicine sprays, and might better be termed mixers or atomizers than carburettors. Since, however, the liquid after being sprayed, is intended to be vaporized before ignition, a common and correct term for this device is vaporizer. There are many modifications of this device but in general it consists of a small gasolene chamber in which the level of the liquid is controlled more or less perfectly, by a float, the chamber being vented so as to permit admission or abstraction of liquid without establishing a compression or vacuum.

From the float chamber a small passage, usually controlled by a needle valve, leads to the spraying tube, which is so placed that the air

drawn in by the suction stroke of the engine must pass the point of the tube, and in passing, suck out and spray the gasolene in the required manner. In order to give the air greater speed and a more powerful

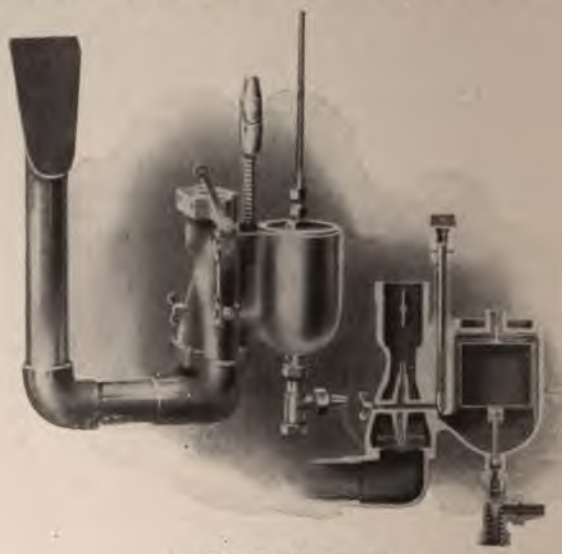


Fig. 17. Carburettor.

effect, it is customary to make the air tube contracted at the point where it passes the spray tube, although very satisfactory vaporizers have been produced without this modification. Since at high speeds the liquid gasolene flows more than proportionately fast as compared

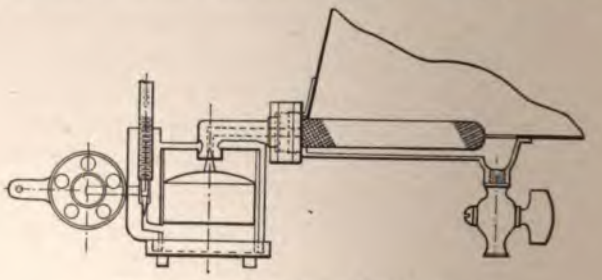


Fig. 18. Sectional View of Carburettor.

with the air, it is quite common to provide a light valve, spring closed, to be opened by the increased suction as the speeds increase and to admit air in proper quantity to compensate for the increased amount of gasolene. This valve in some forms is actuated by a large dia-

phragm, as in the Krebs, and is sometimes provided with a dash-pot.

In some vaporizers the air and gasolene openings are varied by the throttle, which is also varied to control the speed of the engine, and since the screw threads, or devices controlling the variation, may be made as desired, a fairly constant quality of mixture may be secured from vaporizers of this type, subject, however, to the fault that if the throttle is open wide but the engine running slowly, the adjustment intended for high speed will be in operation at low speed, and thus is not so satisfactory as an automatic suction-operated arrangement. The early Kingston carburettor was of the throttle-controlled type. In still another type, of which the Duryea is an example, the air-flow passes through an opening fixed in size except for starting, but the gasolene-flow is varied by lowering the level in the float chamber at high speeds. This is accomplished by the use of a chamber slightly larger than the float, so that little or no reserve gasolene is carried, and this is drawn out immediately at high speed, causing the float to fall and open the passage into the float chamber. The float is provided with a long taper point which requires a considerable movement of the float, in obedience to the considerable variation of the gasolene level, in order to supply the amount of fuel needed at high speed.

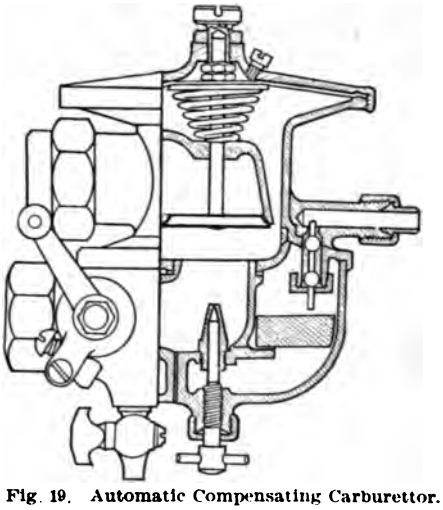


Fig. 19. Automatic Compensating Carburettor.

In still another form, invented by Dunlap, of pneumatic tire fame, the gasolene passage is impeded by a saw-toothed wire, against which teeth the gasolene, at speed, impinges with such violence as to obstruct its flow and lessen the amount passing from the spray tube. Still another form of mixing device does not use the float chamber, but admits the air and gasolene through proportionate valves closed by a spring and opened by the suction of the motor with consequent

admission of proportionate amounts of liquid and air. The original Winton and the Lunkenheimer generator valves were of this kind.

Vaporization. The vaporization of a liquid requires heat, which, in the case of a gas engine vaporizer, is usually obtained from the air with the result that the temperature is decidedly lowered where the vaporization takes place, viz., between the spray tube and the engine, principally near the spray tube. If the atmosphere contains much moisture, this cooling effect causes a deposit on the walls of the vaporizer or its tubing, which is frequently frozen, forming slush or white frost, sometimes to such a degree as to actually close the passage and prevent further formation of proper mixture, with consequent stoppage of the engine. To prevent this and to insure a more homogeneous mixture, heat is usually supplied by drawing the air from near some heated portion such as the exhaust pipe or exterior walls of the cylinder, or by applying heat to the outside of the vaporizer or pipes by directing some of the exhaust gases against them, or by surrounding the parts with warm water from the water jacket. No method secures absolutely perfect results, for atmospheric conditions vary so widely from day to day that only constant readjustment can meet the varying conditions.

Vaporizer troubles are usually due to improper adjustment, the mixture being either too poor or too rich. If the engine will run, the adjustments can be varied and the result noted, while over-rich mixtures will be quite apparent by the odor of carbon monoxide in the exhaust. If the engine will not run, test the mixture in the cylinder by removing a spark plug or peep cap and applying a flame, being careful not to get fingers or face in front of the opening. If the mixture burns bluish with little violence, it is too poor, but if it burns yellow and slow, it is too rich. A proper mixture explodes with a violent outrush of gas.

Frost in the air tube will so obstruct the passage as to prevent the entrance of a new charge and produce loss of power much like a choked muffler. A little hot water will quickly warm the pipe. Water or ice in the gasolene will cause trouble unless removed. The water frequently manifests its presence on rough roads, and a drop of water in a passage—which will not obstruct the flow—has, when frozen, completely shut off the gasolene. Dirt particles also must be guarded against.

Excess Cooling. Since the auto engine is a heat engine it is desirable that it be as hot as is permissible, in order that the heat may be utilized for work instead of passing into cold walls and being wasted. It is well known that a cold engine runs with little power until warmed up, and while part of this lack of power may be due to the stiffness of the lubricating oil,—since this is intended to resist a high heat and must be of high fire-test and of considerable body—much of the lack of power is due to the cooling effect of the cold walls, which absorb the heat from the burning explosive charge and reduce the pressure that, with hot walls, would be expended in doing active work against the piston. Tests have been made which show that a very perceptible increase of power results from the use of hot water for cooling instead of cold water, and stationary engineers who have permitted a flow of water through the water jacket so rapid as to keep the jacket and walls cool enough to not be uncomfortable to the hand, have found a very decided increase in power when the water was caused to flow more slowly and leave the jacket substantially at the boiling temperature.

It is now generally admitted that a temperature slightly below boiling is most satisfactory where water is used for cooling; for if the water does not boil, no steam is formed, and no parts in the water jacket are left without water, with possible danger of overheating. These facts, now well-known, prove the theory that a heat engine should be run hot in order to give most efficient results, and it is the aim of designers to so design their productions that no parts shall be over-hot but that all shall have as high a temperature as is permissible. The principal limitations are premature ignition and faulty lubrication.

Premature Ignition is objectionable because of the negative work done on the piston before it passes the dead center, which not only results in lost power, but usually in a decided knock or pound, annoying to the passengers and destructive to the bearings. Since a poor mixture ignites less easily than a rich one, premature ignition can be frequently lessened and sometimes avoided by varying the quality of the mixture—a proceeding which also adds to the economy. Since compression heats the explosive charge, nearly proportionate to the amount of the compression, an engine designed to run hot should have a large compression space with consequent low compression. The increased economy of the less rich mixture in conjunction with the

hot cylinder walls largely balances the loss of power, due to the lessened compression and since the engine with low compression runs steadily with a smaller fly-wheel, there is a perceptible saving in weight in a motor vehicle and consequently less need of power.

It is also apparent that with a high compression and a small compression space, the pressure at the beginning of the stroke is very high but falls rapidly because the length of the stroke is quite large as compared to the size of the compression space, whereas with a low compression the initial pressure is not high and the compression chamber is of large volume as compared with the length of stroke, so that the pressure is reduced less rapidly and the result is more nearly like that given by a steam engine than is the action in a high compression cylinder.

Because of these facts a low compression cylinder, rather large for the power required, but because of the low compression, light in all its parts, including fly-wheel, and designed to run comparatively hot, is considered best for auto work by many good authorities. It has been frequently noticed that an air-cooled engine, will, for a short period, develop more power than a water-cooled, and this is explained by assuming that the walls become much hotter than the temperature of boiling water, on which account the engine is more efficient up to and until the point of overheating is reached. After this, loss of power occurs, either because of premature ignition or lack of lubrication, or possibly, because at very high temperatures, the cylinder walls or the piston warp sufficiently to no longer fit each other and thus permit the escape of the gases with consequent loss of power. While higher temperatures may be with advantage used in future, it seems safe to assume that in the present state of the art, a temperature not greatly in excess of boiling water, is most preferable in present auto engines.

Lubrication. Faulty lubrication of an engine cylinder may be due to the improper fire test of the oil, to improper methods of applying the oil to the surfaces requiring lubrication, or to improper fits between those surfaces, which permit the escaping gases to blow the oil away from the surfaces, leaving them dry and therefore increasing their heat, both by the friction of the nonlubricated parts and by the heat of the escaping gases which is absorbed by the parts. It is now pretty generally recognized that auto cylinders require oil of the high-

est quality, and that cheap and dirty oil sometimes sold as gas engine oil, is not suited for this work.

An oil suited to steam engines using superheated steam, will in almost all instances, give excellent satisfaction in auto engines. The makers of the vehicle will gladly advise what oil should be used in connection with their product, and when a good oil is once found, it is wisdom to continue its use. If an oil is too thin it does not protect the metal surfaces properly and does not make a good packing nor properly assist the rings in holding the pressure. If of too low fire-test, it boils away as a blue smoke or vapor and leaves the surfaces dry, frequently causing them to cut, and sometimes ruining the cylinder or stopping the motor. A sudden loss of power without apparent cause may, with good reason, be looked for in the cylinder, since lack of lubrication makes a great difference in the friction of the piston, even though the parts are not cutting or have not seized. An excessively thick oil with needlessly high fire-test has no disadvantage except that being stiffer when cold, the engine is more difficult to start. Such oils are decidedly more economical because they wear longer and need be fed less rapidly. Good auto oils usually have fire-tests ranging from 600 to 800 degrees.

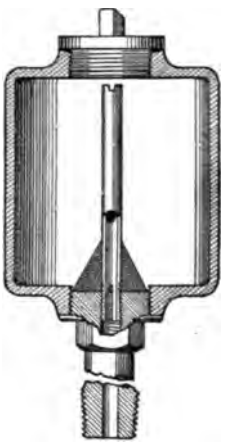


Fig. 20. Lubricator.

If for any reason, proper oil cannot be had, an oil of lower fire-test can frequently be used, but it must be fed in larger quantity and more carefully watched to make sure that it is serving its purpose.

Water Cooling. Consideration of the above facts will show the importance of proper cooling, and something of the loss due to excessive cooling. In a water-cooled engine, the water being unconfined, cannot become hotter than 212° and may, with little trouble, be kept nearly at this point, which is admitted to be most satisfactory, so far as present experience goes. Further, since water in boiling absorbs a great volume of heat, commonly termed latent heat, in its conversion into steam, it is especially adapted to the work of cooling. An increase of work on the part of the engine, with consequent increased development of heat, simply increases the rate of boiling without in-

creasing the temperature appreciably, and thus avoids warping the cylinder wall or vaporization of the lubricating oil.

A most efficient cooling system consists of a tank or reservoir of water above the engine, piped to enter the water jacket on the underside and to return from the water jacket to the tank on the upper side of the engine, which return carries off any steam that may be formed in the water jacket, which steam being lighter than the water, causes the water with which it is mixed to move rapidly upward out of the water jacket and to be replaced by cooler water from the tank. This method of circulation is known as the natural or thermo-syphon method, and is preferred by many designers because of its simplicity. When it is not convenient to use natural circulation, a pump, driven by the engine, is introduced in the circuit and forces the water rapidly enough to nearly or quite prevent boiling under extreme conditions. A forced circulation, however, is not so good as the natural because it is not self-regulating, and therefore if it is fast enough to meet the needs of the engine under extreme conditions, it is usually too fast under ordinary conditions, and results in keeping the temperature of the water in the water jacket much below the boiling point and therefore below the point of greatest efficiency.

Fig. 21. Radiator.

To overcome this objection, some designers employ natural circulation between the engine and the small tank located near and above it, and employ a pump with radiator for the purpose of preventing the water in the tank from getting too hot to condense the steam that may pass into it from the engine. This arrangement gives the benefit of both systems with but little, if any, increased complication.

Since an auto engine of large power develops much heat, a goodly quantity of which passes away through the cooling system, it is quite evident that the water in the tank will soon become boiling hot unless

provision is made for cooling it by the air through which the vehicle passes. It was formerly quite common to provide the tank with air tubes, thus greatly increasing the amount of surface exposed to the air and permitting a more rapid escape of the heat. Other designers employ pipes either plain or with radiating fins, so as to still more largely increase the radiating surface exposed to the air. Still others make their water tanks almost wholly of air tubes, with very small water spaces between, thus getting into a small radiator a great many square feet of cooling surface. In this form of radiator it was found that the natural circulation of the air is very slight because of the small size of the passages, so fans driven by the motor are most frequently used to either draw or force the air through these radiators at a rapid rate and with great cooling effect.

A further advantage of the air-fan in connection with the radiator is that the cooling is not dependent upon the speed of the vehicle nor the force of the wind but is varied by the speed of the motor, and therefore more nearly meets the needs of the motor than any other system excepting the natural system, first mentioned. If for example, as in hill climbing, the motor is running slowly, but with full charges, much heat is developed, but the fan also moves slowly, with very little cooling effect, whereas in the natural system, until the water begins to boil, the circulation is very slow and the more rapid the boiling, the more rapid the circulation becomes. This results in a truly thermostatic circulation, regardless of motor or vehicle speeds, due to the difference in density of the cool water in the radiator and the hot water containing more or less steam in the jacket which is sufficient to meet the requirements of some engine designs. In others, a pump to circulate the water is used.

There have been employed steam condensers in connection with the water jacket by which arrangement no water tank nor pump is needed, because the slight amount of water in the jacket when turned to steam, is condensed by the condenser and at once returned to the jacket. Practically all water-cooled engines form steam at some time, which, not being provided with suitable condensing surface, escapes from the system, thus requiring occasional addition of water. It is considered advisable to have a tank of water above the cylinder jacket, so that the cold water may condense this steam and also always keep the cylinder filled. This tank carries from two to ten gallons.

Most radiators are tubular and on the tubes are fitted and soldered disks of metal, which serve to conduct the heat from the water out to the air, which, by the passage of the vehicle, is thrown against the metal surfaces. These flanges are formed in some instances by crimping a strip of metal along one edge and winding it spirally around the tube, the crimped edge being soldered to the tube. This avoids waste of metal and makes a very efficient radiator. The height of the disk edges above the tube is usually ¼ to ½ an inch or about 10 to 20 times the thickness of the metal, the smaller sizes being most efficient.

In some cases the water tank is cooled by tubes passing through it, which permit a flow of air. These tanks vary from those of large water capacity, having a half dozen or more one-inch tubes, to tanks of small contents completely filled with tubes, either square or round, ½ inch in diameter or less, by 3 or 4 inches long. Such a device is called a cellular or honeycomb radiator, because the tubes suggest the cells of a honeycomb. This type of radiator contains a very large cooling surface, divides the water into thin sheets and is quite efficient, but it is expensive to make, has many joints likely to leak, and the fine passages are easily clogged, on which accounts, the tubular form is now generally preferred. The tubes may be continuous, causing the water to travel the whole length, but later forms use a number of tubes connected at their ends by heads or top and bottom tanks, and the water flowing from one end to the other, is divided, so that a small portion only flows at slow speed through each tube. This arrangement relieves the pump of much of its duty.

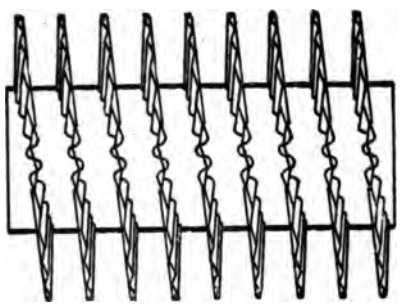


Fig. 22. Radiator with Spiral Flanges.

Air Cooling. Since in any event the heat is dissipated into the air, it is argued by many that air cooling is the most logical form, and many attempts have been made to produce successful air cooled motors. The total heat in the burning charge varies as the cube of the cylinder dimensions, whereas the wall surface varies only as the square; so it has been assumed by many that large engines are of neces-

sity more difficult to cool than small ones, and that air cooling, while applicable to small powers, is not suitable for larger ones. Others maintain, while admitting the above statement as to the total amount of heat, that the heat received by the wall from the gases in the engine must come from the gases adjacent thereto, and that on this account the wall will be little, if any, hotter in the one case, than in the other, and that large auto engines can be cooled just as readily and practically as small ones.

Since, however, the size of engines used in auto work is limited by the weight of the parts and the intensity of the vibrations set up by the explosive charge, it seems quite likely that the latter contention is practically true. It is now no longer common to increase power by increasing the bore of the cylinders, but the accepted method is to increase the number of cylinders, and it was quite thoroughly demonstrated by Knox and others, that cylinders up to 5 inches bore, of varying strokes, can be successfully air cooled.

The most common forms of air-cooled cylinders are either cast with flanges encircling them or machined out of a solid body of stock or forced on by pressure after the cylinder is machined. Other forms have the cooling flanges cast lengthwise of the cylinder. If the engine is horizontal the encircling flange permits the hot air to pass freely away, which is not the case when the engine is placed vertically, unless a fan or some means for moving the air horizontally is provided. For vertical engines using natural air circulation, the lengthwise flanges are undoubtedly best.

Many air-cooled engines are fitted with special forms of cooling surfaces such as threaded pins having one end screwed into the cylinder wall, which pins not only carry the heat outward, but because of the screw threads on their surfaces, are in contact with a large volume of air. Grooves are frequently machined into the cylinder surface, in which are chalked combs or strips of radiating metal having large radiating surface.

In all the larger motors, fans are used to direct a current of air past the radiating surfaces to insure effective cooling.

In some engines, as in the Frayer-Miller, the cylinder is enclosed in a jacket, through which air is forced and by which the air is caused to come in close contact with the heated surface with the result that the cooling is positive, is certain to be effective where needed, and is

largely proportioned to the needs of the engine, because the blower which supplies the air is driven by the engine. In air cooling, however, unlike water cooling, there is no fixed temperature point and there is, therefore, much more variation in the walls of the cylinder, with con-

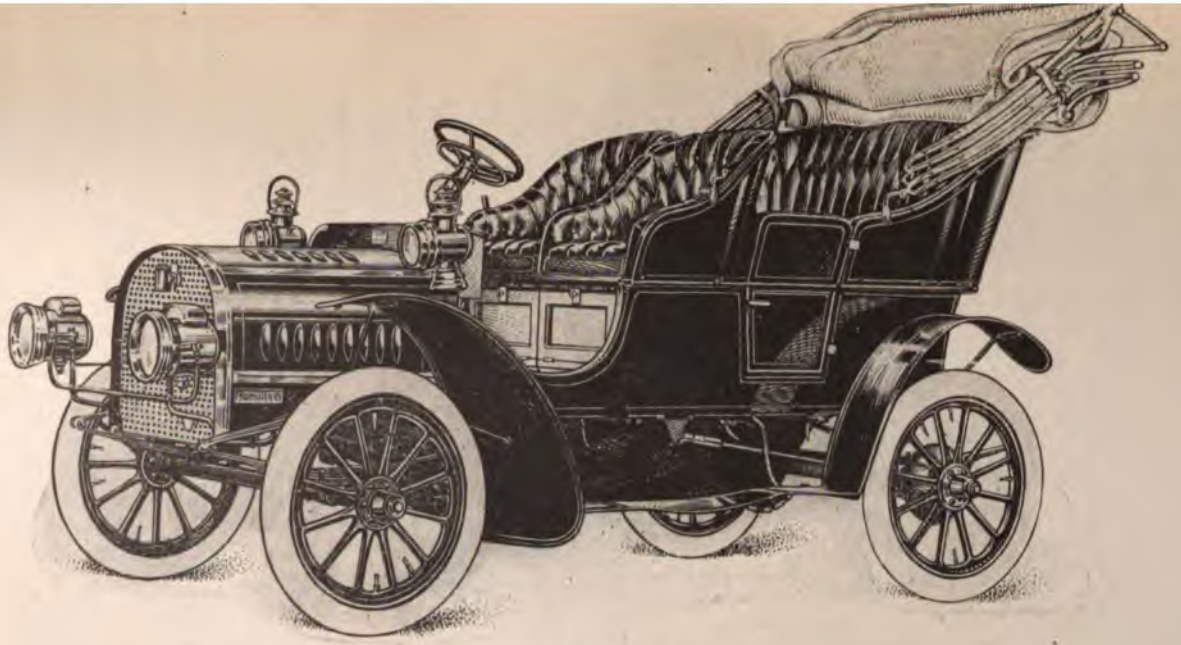
Fig. 23. Frayer-Miller Engine Parts.

The aluminum jacket slips down over the cylinder head, the valves being put in from opposite sides. Air is forced down from the top of the jacket passing equally to all sides, cooling the cylinder without warping.

sequent possible warping, than is found in a water-cooled motor. This variation is believed by many to shorten the life of the engine and increase its troubles, while others argue that the avoidance of the water system more than makes up for the lack in this respect.

CHANGE-SPEED DEVICES

Second in importance only to the motor is the mechanism for conveying its power to the rear axle, or to the propelling wheels. This mechanism consists usually of first, a change-speed device by which the ratio of motor revolutions to rear-wheel revolutions is varied to meet the varying road conditions, such as hills, mud, sand, snow, crowded traffic or clear level roads; second, of a transmitting device such as a shaft, chain, or chains, or belts between the change-speed gear and the rear wheels; and third, of a balance gear often called a



SURREY TYPE OF RAMBLER AUTOMOBILE
Thos. B. Jeffrey & Co.

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differential, or its equivalent, by which the power is divided and caused to drive both wheels, while permitting freedom for the purpose of turning corners.

Change-speed gears are of many varieties, of which the most common are planetary, sliding gear, individual clutch, friction, automatic and several others, combining more or less of the various features found in these forms with possibly slight variations, such as magnetic, pneumatic or hydraulic clutches. Few subjects offer a greater field for ingenuity than change-speed devices, and many forms not worthy of description in the limited space available, have been tried and found reasonably satisfactory.

Planetary Gear. The planetary gear was the first form to be largely used in America, being first regularly employed on Duryea vehicles in 1898 and afterward adopted in the Olds runabout and by its many imitators, as well as in the Cadillac and Ford machines, in all of which it is still found, as well as in many others. In its original form it employed a spur driving gear attached to the crank shaft. Meshing into this was a planetary pinion carried by a stud projecting from a frame journaled on the crank shaft end, which frame carried the driving sprocket. Meshing into the pinion, was an internal gear concentric with the crank shaft, and the device was provided with three clutches, one for locking the parts together, so that all would revolve with the crank shaft, forming direct drive on the high gear; another for holding the internal gear stationary while the pinion rolls around inside it, carrying the sprocket forward at low speed; and a third for holding the pinion frame and causing the sprocket to be carried by the internal gear in a reverse direction as the pinion revolves. (The sprocket having been first released from the pinion frame.)

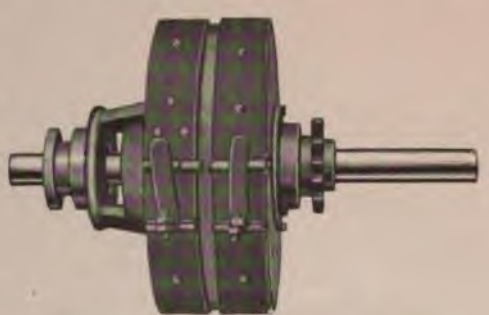


Fig. 24. General View of Planetary Gear.

These clutches were operated separately, only one, as a rule,

being engaged at a time. A single operating lever was usually employed for high and low speed, while a second lever was used for the reverse. Two to four pinions were employed instead of one, which gave added strength without requiring additional room, and thus permitted the gears to be of much narrower face for a given duty than would have been possible with a single form. Modifications of this device employing two or more sets of gears are largely used because

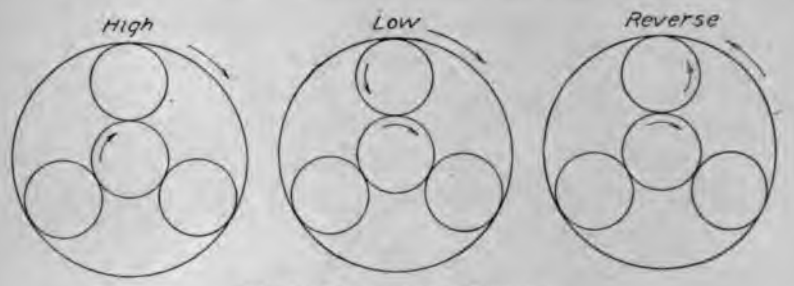


Fig. 25. Planetary Gear Diagram.

All parts locked together, gives high gear and carries the sprocket at same speed as crank shaft without friction or moving parts.

Holding the large internal gear causes the intermediates to roll forward slowly and carry the sprocket with them, giving low gear, one-third to one-fourth the crank shaft speed.

Holding the spindles of the intermediates drives the internal gear in a reverse direction, giving the reverse speed.

the original form was protected by patent, but the principle is much the same in all. The diagram herewith illustrates the action more fully. As usually constructed, the planetary system provides two speeds forward and a reverse, but some forms provide for three speeds forward together with a reverse.

Individual Clutch. The individual clutch transmission is still an older form, having been used by Duryea in '93, Haynes in '95 and by several foreign makers fully as early. This consisted usually of two parallel shafts on which were two or more sets of spur gears of different sizes but of a common distance between centers. Each set of gears was provided with a clutch adapted to cause that set of gears to transmit power at its proportionate speed when desired by the operator. For reversing purposes, sprockets and chain instead of gears were used, or one set of gears small enough not to mesh, but provided with an intermediate, were employed. The individual clutch system permits a wide variety of speeds, smooth and noiseless engagement of any speed, and is a very satisfactory system, its principal objection being the large number of clutches and the fact that all sets of gears are in

motion at all speeds. To avoid clutches some designs employ a single friction clutch and a movable key or pawl by which any gear can be locked to the shaft, and speed changes are made by sliding this key from one set of gears to the next. The strain on the small key results in its rapid destruction and forms the principal objection to

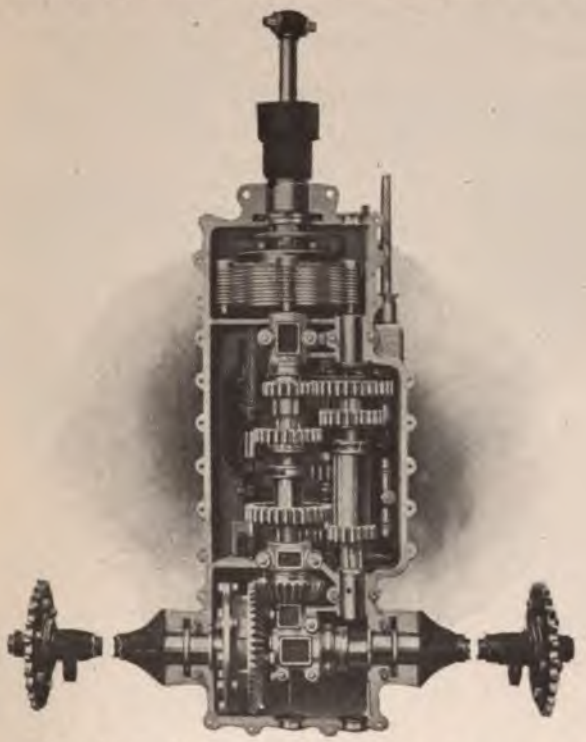


Fig. 26. Clutch, Sliding Gear and Counter Shaft.

this arrangement. Similar results are obtained by sliding the gears themselves, which although not so compact, is considered a stronger and more desirable device.

Sliding Gear. Possibly the most used form to-day is the sliding gear. This, like the other forms, is made in a number of varieties but, in general, consists of parallel shafts, and multiple sets of gears of differing proportions. On one shaft the gears are fixed, while on the other they are commonly attached to a sliding sleeve, which is either fitted to a square shaft or provided with a spline and key-way to prevent rotation of the gears without rotating the shaft, and yet permit

free movement of the gears along the shaft. The gears are placed at such intervals that when one is engaged, the others are disengaged. In operation, a single clutch, generally located in the fly-wheel, is withdrawn while the gears are being shifted, after which the clutch is allowed to engage and propel the vehicle. The ends of the gear teeth are sharpened so that they will engage each other easily and thus permit shifting from one set to another without difficulty. If the

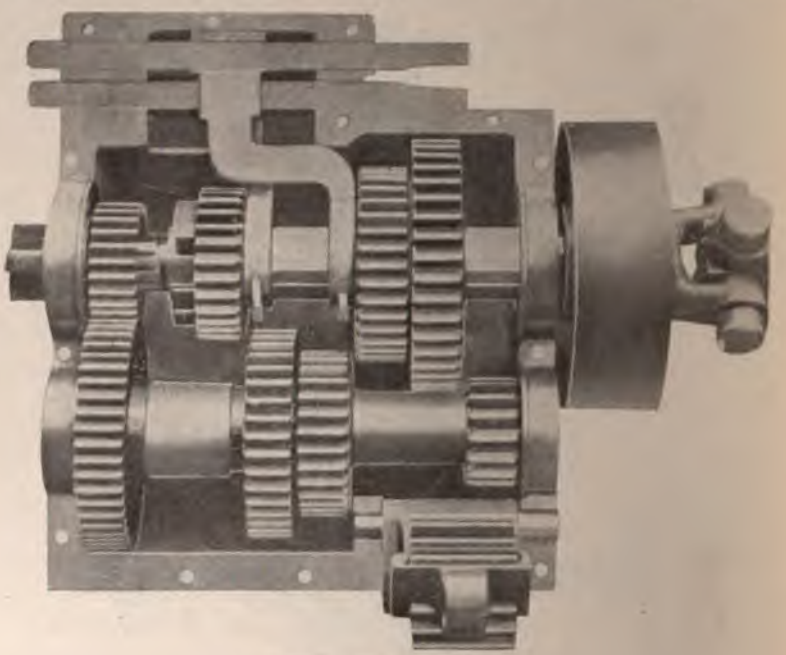


Fig. 27. Sliding Gear Set.

clutch is not fully withdrawn, the ends of the teeth about to engage, strike against each other, often making considerable noise and sometimes breaking the teeth.

In the better forms of sliding gear designs, the main shaft is divided in a gear box, and the power transmitted to the second shaft is, by an additional set of gears, returned to the second part of the main shaft and by it transmitted to the wheels. At one speed, usually the highest one, the two parts of the main shaft are connected by a clutch of the positive or jaw-clutch variety, while the parallel shaft with its gears is completely disengaged and stands idle. This gives a direct

drive, free from needless friction and is considered quite advantageous. In some forms, two of the sliding gears are on one side and two on the other. This, of course, requires two shifting forks in its operation. Other forms employ a shifting fork for each gear and a selective means

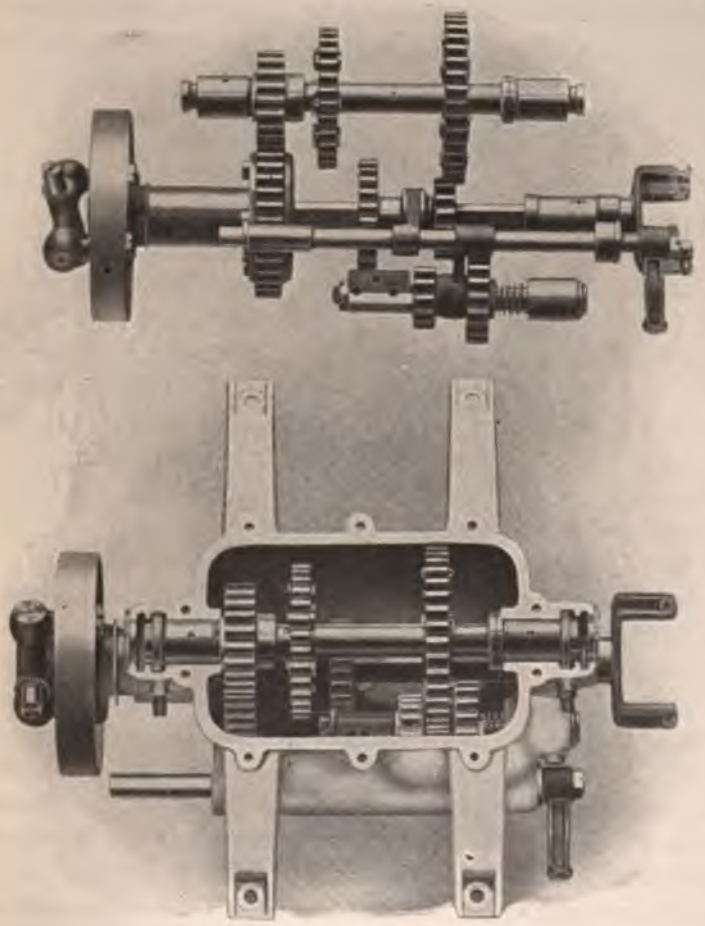


Fig. 28. Sliding Gear Transmission.

of engagement by which the operator can cause the single shifting lever to engage any desired fork, and thus put into operation any gear which is brought out of operation as the lever passes to neutral, where it is again ready to engage any desired gear.

The objections made to the sliding gear device is that this method of meshing gears is unmechanical, wears the gears rapidly, is likely to break them, and the means of shifting is much slower and therefore less safe and handy than the individual clutch or the planetary systems. It is argued, for example, that in the sliding gear the operator must withdraw the clutch, then withdraw the gear, then shift the gear lever, then cause it to engage a different gear and finally complete the operation by letting in the clutch–a total of five movements. In the planetary device the same motion that withdraws the high clutch will, if continued beyond the neutral point, engage the low one and vice versa, while in the individual clutch system one movement disengages the clutch and another, usually of the same lever, engages another clutch, with its corresponding gears; at most two movements, and in many forms accomplished by a single movement.

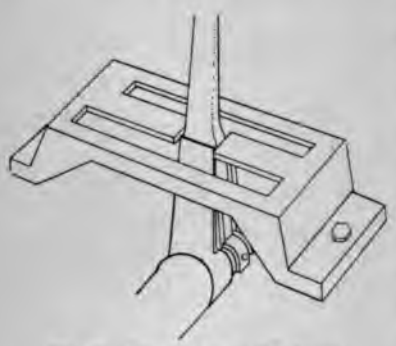


Fig. 29. Single Lever Quadrant, Selective Type.

The importance of quick action in a crowded street or on a steep hill can hardly be overestimated, particularly since motor vehicles are rapidly-moving devices and but little time can be allowed for the performance of any simple function like speed changing. In spite of this disadvantage, however, the sliding gear seems to be increasing in popularity, which is probably due to the fact that many people regard the foreign vehicles as superior to the American, and the sliding gear is a foreign device. It seems also probable that the greater simplicity of the sliding gear system as compared with the individual clutch has caused it to find favor with the makers, to whom simplicity means cheapness, and who are not so much concerned as to whether or not it is most easy to operate. The simple device is not only cheapest for the manufacturer but it is generally more easily understood and maintained by the owner, and should, if other things are reasonably near equal, be given preference.

Friction Gear. The friction gear, although but little used, is an exceedingly old form. It was probably the first form in the thought of

every designer in connection with the gas engine, for in the early days gas engines were regarded as being inflexible, and a flexible driving gear was considered an absolute necessity. Lack of positiveness, the objectionable pressure necessary to secure driving friction, the disturbing effect of grease, frost or water when found upon the friction surfaces, the large size of the discs required, and the constant loss of power due to the fact that variable friction devices cannot be constructed upon rolling cone lines, all conspire to make friction devices objects of suspicion to which most designers were unwilling to confine their efforts. Successful use for many years upon vehicles of even the heaviest weights has proved that friction driving gears are capable of successful use and excellent service, and that their advantages and objections compare favorably with other systems.

Several forms have been used, of which the most common form, and the one longest in use, consists of a disc on the engine shaft parallel to the plane of the fly-wheel and often formed by the fly-wheel itself. Parallel to this disc is a driven shaft on which the driven disc is arranged to slide with its edge in contact with the face of the driving disc. This driven disc can be shifted from the extreme outer edge of the driving disc, which is usually high speed position, to a position which is beyond the center of the driving disc, which is a reverse position. At the center the driving effect is nothing and the driven disc would stand still but is usually disengaged at this point. This form has been in use for five years on Union vehicles and has been thoroughly tested under every condition of road service.

A modification employs two additional discs, one journaled on the cross shaft with its edge engaging the reverse surface of the driving disc, the other journaled independently on a short shaft in line with the driving shaft and with its outer surface engaging the edge of its mate, while the driven disc engages its face opposite the point of engagement on the driving disc. This arrangement applies power to the driven disc at opposite sides, which balances the pressure and increases the driving effect to a considerable extent.

A modification of these forms reverses the positions of the discs and employs the shifting disc as the driving device with its edge moving across the surface of the driven disc. This reversal secures great power at low speeds, but for pleasure motor vehicles this is not so desirable, for they are usually driven on the high gear, depending upon

the throttling of the engine for necessary variations in speed, and friction discs of this arrangement are quite wasteful of power when the transmission point is near the center of the disc surface. This is because of the fact that the point of contact is not actually a point, but covers a considerable surface, on which account a considerable slip and loss of power results. This slip is dependent both upon the width of the friction edge in contact with the disc and upon the curvature of that circle of the disc in contact at any particular time.

If we assume the contact surface to be more or less elliptical in shape, it will be seen from the diagram that the surfaces must slip in

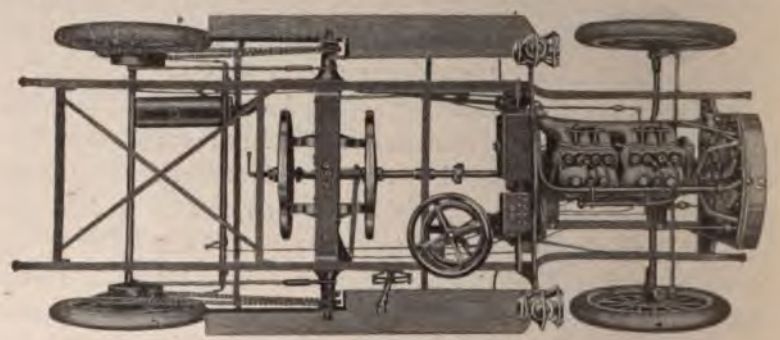


Fig. 20. Windsor Friction Drive.

opposite directions on opposite sides of the center of the contact area, and that this slipping is both across and with the edge of the driven disc.

A third form of friction in use on the Windsor vehicle is a modification of the second form. In this the driving shaft is equipped with two discs between which is placed two halves of a cross-shaft, each equipped with two edge-driven discs. These half shafts are so mounted that their adjacent ends can be thrown in opposite directions and the discs on them are likewise mounted to move oppositely and in like proportion. Since the driven discs are on opposite ends of the driving shaft, it is obvious that if one is thrown forward and the other backward, both will be rotated in the same direction, whereas if they are thrown in the opposite direction a reverse motion will be given. This obviates passing the center of the driving disc to secure a reverse, and since it is seldom or never necessary to have an extremely slow speed, the driven discs need not be shifted greatly to produce the

variations in speed, which is done by shifting them toward or from the other edges of the driving discs. The illustration makes the arrangement plain without further explanation. The amount of clearance is so slight that the movement of the half shafts out of a direct line is too little to have any practical effect of a detrimental character.

A fourth form is arranged to make use of the friction drive only for such variations in speed as are necessary below direct drive, and

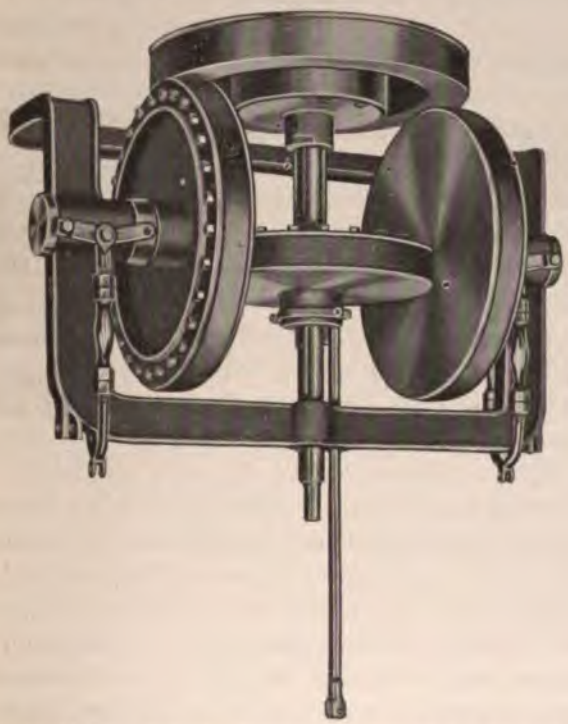


Fig. 31. Friction Drive for Variations in Speed below Direct Drive.

secures the advantage of direct drive without loss for high speed work. This arrangement seems particularly adapted to pleasure vehicle service and will doubtless find large adoption in future. In this construction the driven disc stands parallel to the fly-wheel and is shiftable toward and from the fly-wheel surface. The edge of the driven disc engages the plain surfaces of two or more intermediate discs, journaled on short shafts parallel to the plane of the fly-wheel. The edges of these intermediates engage the fly-wheel by gear or friction as may be,

and transmit power to opposite sides of the driven disc. Shifting from the center of the intermediates toward the fly-wheel increases the speed, while in the opposite direction beyond the center gives the reverse. When near the fly-wheel a clutch is engaged, which connects the fly-wheel and driven disc positively after which the intermediates are disengaged, leaving direct drive on the high gear.

VEHICLE CONTROL

With all these devices the operator is called upon to perform certain operations, such as setting and releasing clutches, shifting the discs in and out of contact, or shifting and selecting the gears to be used. In the operation of the vehicle, he must have in mind the important function of speed changing, in addition to the equally important ones of steering and throttling the motor, together with minor functions such as spark management, lubricator oversight, and tooting the horn or sounding a gong, which is frequently required by law. Such a multiplicity of duties is confusing to many operators accustomed only to drive a gentle horse, which requires but guiding and speed regulation, and there is no doubt but that many accidents are due to the operator in an emergency becoming confused and failing to do the right thing to prevent trouble.

It is, therefore, quite necessary that vehicle control should be as simple as possible, and while some designers have eliminated minor details, such as spark control, and the necessity for watching the oil or water circulation, and have reduced the operation of the vehicle to steering and throttling, with sufficient power to drive a large and flexible engine almost wholly on the high gear, and without speed changing, others have eliminated speed changing entirely by making it automatic. Thus in the Sturtevant machines, the fly-wheel is provided with two or more sets of governor weights. When the engine is throttled extremely low, these weights are all drawn in by springs and all drives are disconnected, leaving the vehicle standing still. If the motor is speeded up, the lightest set of springs permit one set of weights to throw into engagement the low speed gears, and these continue in engagement until the vehicle attains considerable speed, when a second set of weights throw out, bringing into action a higher gear, which drives the vehicle at a higher speed. The lower speed gears

become inoperative because of a ratchet provision which permits over-running the low gears, whenever the driven part acquires a speed above that imparted by the low gears. If the speed decreases, the high speed weights are drawn in by their springs and the low gears take up the work, until, as when stopping, they too become inactive because of lack of speed. This arrangement eliminates speed changing entirely and renders the vehicle more suited to the use of every member of the family than are most vehicles—a condition that sooner or later must come to pass.

Combination. In a few vehicles the motor has been used direct connected to a dynamo to generate electricity, which, either through a storage battery, or direct to a motor, is used to produce the necessary speeds. This system has not been largely applied to pleasure vehicles, but has seemed best adapted to commercial vehicles where, because of widely varying loads, widely varying powers are needed, and the electric motor not only provides a steady application of power, but in connection with the storage battery, is capable of great exertion for short spaces of time, and undoubtedly does give an almost ideal method of speed changing. The added cost and weight of a double system of this kind is quite likely the chief argument against it.

It has also been proposed to use pumps for water or oil directly attached to the engine, while a motor adapted to be driven by liquid was directly connected to the rear axle. Such a device, while doubtless flexible and smooth running, is admittedly inefficient and not easily maintained in proper working condition.

CLUTCHES

Since the gas engine must be started from an outside source, and runs with but little power when cold, it is practically necessary to have a clutch by which the engine can be disconnected from the driving gear or at least from the propelling wheels. The forms of these clutches are quite varied. In connection with the sliding-gear change-speed device the clutch is usually placed between the fly-wheel and the change-gear box and is generally of the conical variety, one member forming part of the fly-wheel and the other being attached to the shaft entering the gear box. One surface is usually faced with leather or similar material having a high friction coefficient, and a

strong spring is arranged to hold the members in engagement. A pedal like a brake pedal is usually provided to withdraw the driven member, with a ratchet for holding it withdrawn while the motor is being started.

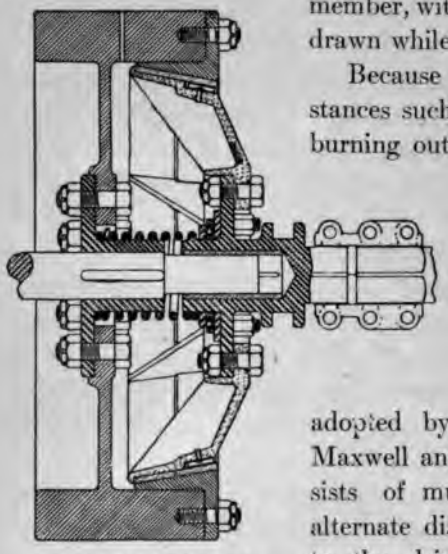


Fig. 32. Conical Clutch.

Because of the rapid wear of soft substances such as leather, and the danger of burning out the clutch surface in a few minutes after a clutch begins to slip, as well as because of the objectionable size necessary to secure an effective clutch of this kind, a better form of clutch has been recently adopted by leading makers, such as the Maxwell and Stevens-Duryea. This consists of multiple discs of metal, each alternate disc being attached at its edge to the driving member and the other discs attached at their centers to the driven member or vice versa. Light springs cause these to separate sufficiently to be clear of engagement when the clutch is released. The total amount of surface is so large that the friction coefficient may be very small. This form of clutch generally runs in oil, has no appreciable wear, needs no adjustment and the very worst that can happen is to burn out the oil between the discs and thus greatly increase their friction coefficients.

Fig. 33. Pedal and Ratchet.

A very common form of clutch consists simply of a band, frequently lined with leather, vulcanized fiber, or even canvas, which is provided with means for causing it to grip the surface to be held. This form is commonly used in connection with planetary gears and is much employed as a brake device.

In another form of clutch the surface to be gripped is not on the outside, as with the band, but is an inner circumferential surface, and two or more shoes or short segmental sections are caused to press

against this inner surface by toggles operated by a collar shifted lengthwise the shaft. This is one of the earliest forms of individual clutches, and was used by Fawcett in an omnibus driven by an internal combustion engine at Pittsburg in 1876. A great variety of modifications of the devices just described are to be seen in use to-day, but with a knowledge of these most important forms the modifications are easily understood upon inspection. Square-jaw or positive clutches are used in some instances, as in the White steamer or the Chicago friction drive, and serve to change the speeds. Such clutches are used in some change gears instead of sliding the gears.

Fig. 34. Multiple Disc Clutch.

TRANSMISSION

After passing the change-speed gear, the power is transmitted usually to the balance gear, and for this purpose the single chain is the most common form. This is so simple as to need but little description,

Fig. 35. Stevens-Duryea Fly Wheel, Crank Shaft and Disc Clutch.

being known in its simplest and most successful form on practically all bicycles. The front or driving sprocket is usually small, the larger or driven sprocket being several (three or four) times the diameter of the front.

The block chain adopted from bicycle service was the first form used on American motor vehicles, but being of bicycle size in almost every instance, was found totally inadequate and was therefore almost universally condemned. Not only the chain but the sprockets were too small, with the result that both wore out quickly and breakages

Fig. 36. Duryea Chain with Felt Lubricator.

were frequent. The block chain has less parts than the roller, has less joints to gather grit, is less noisy and, if of proper strength and properly fitted to the sprocket, runs with as little friction and transmits power with as great efficiency as any device yet offered. Few block chains are in use to-day, but of the few, the Duryea is noticeable because the blocks are bored transversely, so as to just intersect the rivet holes, and this transverse bore is filled with a felt pad, which absorbs oil and keeps the rivets properly lubricated. The value of oil upon any bearing is self-evident, and this arrangement not only insures oil in the proper place, but permits the outer surfaces of the chain being kept clean and practically free from grit, so that the rivets are not likely to wear in their bearings, nor do the teeth of the sprockets wear so rapidly as usual.

The roller chain is the most common form and is so called because each rivet passes through a bushing around which bushing a roller is placed, so that the chain pull is taken by the roller bearing against the bushing, while the rivet is journaled inside the bushing. The reason for this is that as the chain lies down in its place upon the face of the wheel, the roller rolls down the teeth instead of sliding, but this reason is based upon chain imperfections and is not a proper one in connection with good chains and properly cut sprockets. If the chain and sprocket fit

Fig. 37. Roller Chain.

properly, the pitch of the chain is slightly less than that of the sprocket, so that the rollers or blocks rise and fall out of and into their places, as the sprocket revolves, without friction. If, however, the chain is over-pitch, it will be loose at the middle of its length of contact on the sprocket and will grind and bind where it comes in contact and where it leaves the sprocket, and while rollers may partly overcome this grinding, the loss of power in any event, is decidedly objectionable, and such chains should not be continued in use.

It is to overcome this defect in driving chains that self-adjusting chains, like the Renold silent and the Morse silent chain, have been put upon the market. These have not come largely into use on autos because of their high first cost, but they are undoubtedly most meritorious, as they wear as long as gears, are more flexible, are less noisy,

Fig. 38. Morse Silent Chain.

transmit as much power for a given width of tooth and need no more attention than gears. Their decided advantage is in the shape of the link, which causes the chain to select its own pitch line on the sprocket. Because of this feature they do not stretch and get out of pitch as do chains of ordinary construction, but any stretch of the chain, due to the wearing of the pivots, is compensated for by the fact that the chain automatically takes a larger pitch line position on the sprocket, whereas in chains of the usual kind an increase of pitch causes the chain to grind and rapidly wear the tooth surfaces, as the chain takes its position on the sprocket with much loss of power and with an increasingly rapid destruction of both sprocket teeth and chain.

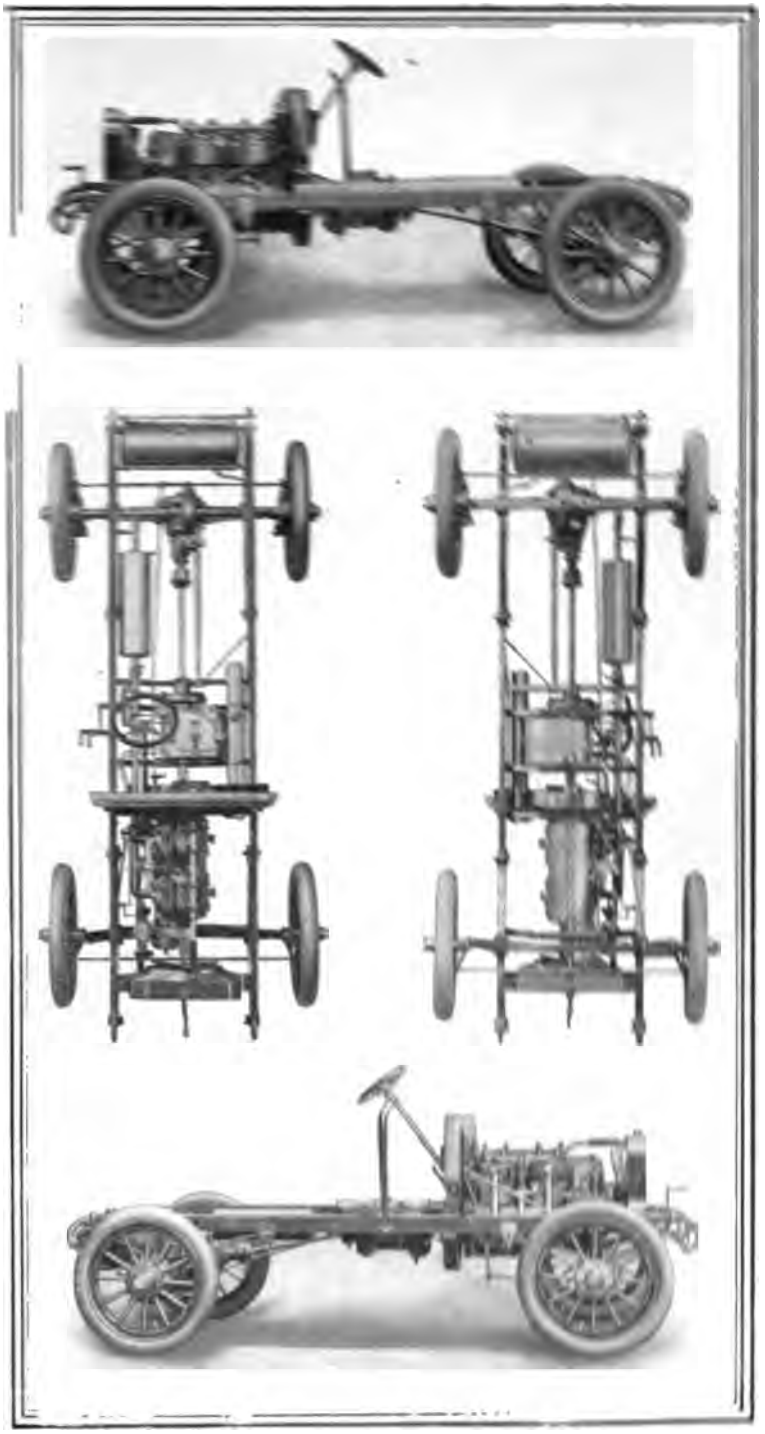
The pitch of a chain is the distance from center to center of similar rivets, having one chain link between them. In roller and the silent chains mentioned, it is the distance between rivets. In block chains each link is composed of one block and two side pieces, which are held

together by a rivet, so that the pitch of the chain is the total of two spaces adjoining. This pitch distance is measured in a straight line forming one side of a polygon having as many sides as the sprocket has teeth, and corresponds to the older and now less used circular pitch as applied to spur gears. In circular pitch the gears were measured from center to center of tooth, just as sprockets are measured, these measurements being taken on the pitch line. In the later and more common method of measuring gears, the pitch is expressed by the diameter of the gear at the pitch line. Thus, an eight-pitch gear has eight teeth on its circumference for each inch of diameter. The pitch line of a gear is about midway of the tooth and is the line common to both gears; similarly the fixed line of the sprocket and chain is the line of the rivet centers as the chain lies upon the sprocket.

Although less applicable to belting, the pitch line of a belt is approximately at its center and should be taken into consideration when considering pulleys for belt driving.

In some vehicles more than one chain is used, either from the motor shaft to the counter shaft, as in the Holsman,—which employs chains for its change-speed device—or as in many forms of large vehicles which employ two chains from a counter shaft to the rear wheels. The counter shaft is parallel to the rear axle but in front of it, and is fitted with a sprocket on each end, in line with the large sprocket on the corresponding rear wheel. This construction is usually applied to heavy vehicles, and in this construction the balance gear is in the counter shaft and power is frequently transmitted from the change-speed gear to the balance gear by propeller shaft.

Chain troubles usually consist of broken links or sheared rivets, due quite frequently to something getting between the chain and sprocket and thus subjecting the chain to undue strain. If the chain is quite loose, it may climb on top the sprocket teeth with the same result. As the chain wears and increases its pitch length, the tendency to climb the teeth is increased and it will run with a grinding noise, indicating rapid wear. A block chain can usually be reversed with good results after it is partly worn. Extra links are usually carried for repair purposes, and some chains have their rivets button-holed into the side links, while in others the rivets are held by cotter pins, so as to permit quick repairs to be made.



GROUP OF MODEL K CHASSIS
The Winton Motor Carriage Co.

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Chains have been condemned because they have been abused, whereas if properly designed, cased, and cared for, as is necessary with gears, they will give as good or better service.

The propeller-shaft transmitting device is so named because of its resemblance to the shaft used to transmit power from the motor to the screw propeller in boat service. At its forward end it is driven by the motor or change-speed gear just as in a launch, while at the rear end it is fitted with bevel gear usually of small diameter, meshing into a larger bevel gear on the rear axle or counter shaft at right angles

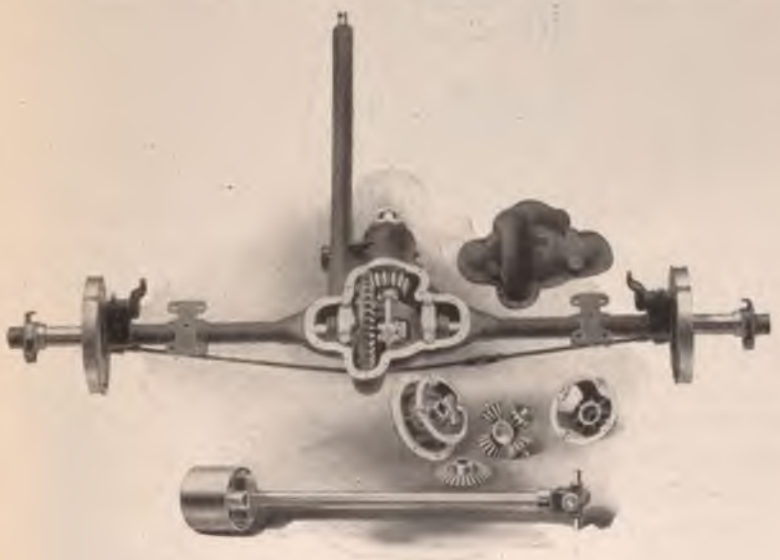


Fig. 39. Propeller Shaft Transmitting Device.

to the propeller shaft. In some cases a worm gear is used instead of the bevel, while in others equivalents having pins and rollers instead of teeth are employed, the aim being to reduce the friction of the bevel gear. The bevel gears are commonly encased to hold oil and keep out the dirt, and this casing contributes very largely to the good service given by such gears. In all bevel gears there is a decided thrust against the bearings, which must be strongly resisted if the gears are not to become separated at their pitch line, causing increased noise and friction.

Gimbal Joints. Because of the impossibility of holding the motor at the front of the propeller shaft and the gears at the rear in alignment with each other, it is common to provide the propeller shaft with knuckles or gimbal joints, which, while transmitting power perfectly, permit the shaft to yield and change its direction ten or even twenty degrees. The propeller shaft is usually provided with a telescopic joint which permits it also to vary in length between ends, and these two accommodations allow the springs of the vehicle to perform their function without interfering with the transmission of the power. A great variety of gimbal joints have been employed and the same is true of the telescopic joint. These joints are frequently encased in leather cases packed with hard grease, which both keeps out the dust and insures lubrication.

Fig. 40. Gimbal Joint.

Radius Rods. The propeller shaft is frequently paralleled by a torsion rod or bar having sufficient stiffness to resist the push of the bevel gear as it transmits the driving effort to the axle. In any event, this strain must be resisted by some means, and in connection with chains it is manifested as a forward pull parallel to the chain, which is taken by distance or radius rods arranged to extend from the driven axle to, or nearly to, the driving one. In some faulty con-

Fig. 41. Roller Bevel Gears and Universal Joint.

structions the distance rods are attached at one end or the other some distance away from the axle centers with the result that the spring action gives rise to a travel of the axle not coincident with an arc drawn around one axle center and passing through the other, and the result of this lack of proper movement is either to loosen the chain or tighten it, resulting frequently in the chain running off or being strained so forcibly as to break it.

Balance Gear. The balance gear, frequently called differential, or jack-in-the-box, is a device intended usually to transmit the power from the sprocket or bevel gear to each half of the countershaft or rear axle and thus to each wheel equally at all times, regardless of whether the wheels are turning at equal speed on a parallel course, or one slower than the other, as in turning a corner. In its simplest form it consists of two large bevel gears attached one to each half of the rear axle, which carries at its outer ends the driving wheels, or in the case of the countershaft, the sprockets for the side chain. Between these large bevel gears is journaled the driven sprocket or driven gear, the hubs of the bevel gears forming the hubs in many cases. In this sprocket or gear are one or more pinions, usually three or four mounted substantially upon spokes and arranged to mesh into the large bevel gears of the balance gear.

In theory each of these pinions is simply a lever receiving the pull of the chain at its center and because its ends (opposite teeth of the pinion) engage the opposite bevels, it transmits half of the pull received to each of the bevels When the vehicle runs on a straight course the pinions and bevels revolve as a solid mass without relative motion, but if, as in turning a corner, one bevel and its corresponding rear wheel takes a slower motion, that end of the lever (pinion tooth) is retarded, while the opposite end of the lever (pinion tooth) moves forward more rapidly, driving the outer wheel of the vehicle with increased speed. In all cases the amount of force applied to each wheel is the same, since both ends of the lever are of equal length, the only variation being a slight loss by friction, due to the motion of the parts of the gear in relation to each other. While the bevel gear is the simplest form, many balance gears are constructed by the use of spur gears because spur gears are manufactured more cheaply. In this form each half-axle

is fitted with a spur gear, while the sprocket is provided with studs or bearings parallel to the axle on which are journaled long spur pinions, usually of small diameter. At their inner ends, these pinions mesh into each other, but one projects to one side of the sprocket, the other to the other side, and these projecting ends mesh into the spur gears. The power transmitted to the sprocket is, by the teeth of these pinions, transmitted equally to the spur

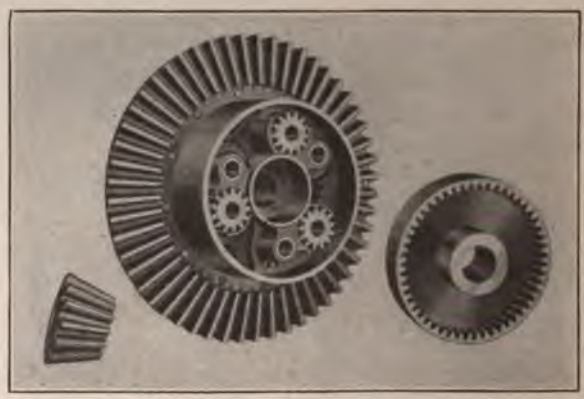


Fig. 42. Spur and Internal Balance Gear.

gears in which they mesh, while variations in speed are met by the rotation of the pinions in opposite direction, which accomplishes the same result as the rotation of the bevel pinion.

A third form of this device now little used, employed a spur gear on one half axle, an internal gear of larger diameter on the other half, with a single spur pinion meshing into both and mounted on a stud projecting from the sprocket. The pull of the sprocket was transmitted by this stud and pinion equally to the large internal gear and the small spur pinion, but since the point of application or pitch line of the internal gear was farther from the axle center than the pitch line of the spur gear, the effect was to drive the one wheel more strongly than the other. This arrangement is particularly advantageous where the resistance to be overcome is greater on one side of the vehicle than on the other, as for example in the three wheeler having the third wheel arranged to track with one of the drivers, for it differentiates or transmits the

power in different proportion, whereas the usual form being balanced, is really a balance gear.

Other devices are in use to transmit power to both wheels, as is necessary to secure traction and a forward movement without a tendency to shift to one side, and most of these aim to avoid the balance gear. The objection to the balance gear aside from its cost and weight is principally that if one wheel strikes a slippery spot, as a piece of ice, and slips backward, no power is transmitted to the other wheel and propulsion ceases. This is because the slipping wheel moves at double the angular velocity of the sprocket instead of at the same velocity as would be the case if both wheels were revolving at the same rate of speed.

In one or more types of friction-drive vehicles two driving discs are used and no balance gear is employed, it having been found that the friction discs will slip sufficiently to permit satisfactory turning, while on the other hand, if one vehicle wheel slips, the driving ability of the other is in no wise lessened. In the rope-driven Holsman, and one or more of its type, the slip of the driving ropes is utilized in a similar manner. The Hedgeland solid axle not only does away with the loss of strength or the increase of weight, due to the use of half axles, but it secures a positive drive to the slow wheel and thus avoids loss of traction by the slipping of one wheel. In this device each end of the axle is provided with a clutch fitted to the wheel hub so as to remain free when the wheel moves faster than the axle or when the axle stands still with reference to the frame of the vehicle. A forward movement of the axle causes the clutch to grip the wheel and drive it forward, but at all times

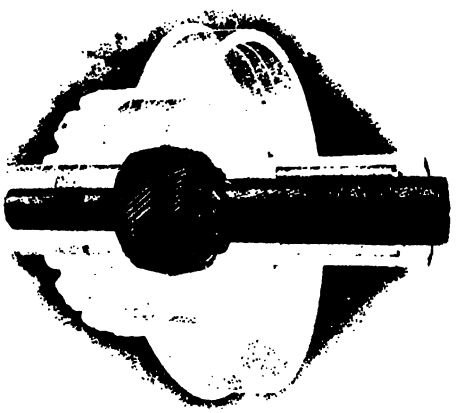


Fig. 43. Hedgeland Solid Axle.

the wheel is free to turn with greater angular velocity than the axle and thus releases itself.

In reversing, the same action results in the opposite face of the clutch being brought into service, while in coasting the vehicle runs free without the necessity of turning the rear axle and propelling mechanism.

Rear Axle. Directly connected with the balance gear is the design and construction of the rear axle. A quite common form consists of two half axles passing through the tubular half frames, which are bolted together around the balance gear forming the balance gear box, frame or spider. Each half axle is a duplicate of the other as in each half of the rear framework, and each is

Fig. 44. Rear Vertical and Horizontal Views of Shaft-Driven Rear Axle.

provided with bearings at the inner end near the balance gear and at the outer end adjoining the vehicle wheels. In some construction the balance gear is not exactly at the center but is at one side, making one of the rear axle parts and the tubular portion of its case shorter, while the opposite parts are correspondingly longer.

A second form of axle employs a full length axle, having fixed, generally near one end, one of the balance gears, while slipped over this end, is a sleeve, carrying the other balance gear. The outer end of the sleeve on one side and the outer end of the axle on the other are fitted to the corresponding vehicle wheels. A nut on the sleeve end of the axle holds the sleeve in position, and sometimes also holds the wheel in place, the whole forming a simple and satisfactory construction. Both of these forms are

what is known as "live axles," *i. e.*, axles which revolve with the wheels. They are advantageous in that the use of a single sprocket is permitted, and this may be placed in under the vehicle, thus bringing the chain away from the dirt of the wheels, where it is less unsightly and more durable. The disadvantage of the live axle is that it must be quite strong to properly carry a given load, because in revolving it is subjected to stresses in opposite directions, and is therefore likely to be broken.

Dead axles are commonly used on heavy vehicles, and these are substantially the same as on horse vehicles. With this construction each driving wheel is fitted with a sprocket from which a chain runs, usually forward, to the projecting end of the countershaft. The balance gear and axle constructions heretofore described, apply, with slight modifications, to the countershafts, which, because of the gear reduction between the countershaft and the rear wheels, need differ only in that they are not so strong and heavy.

Front Axle. The front axle of a motor vehicle differs usually from horse vehicle construction in that there is no fifth wheel at the center of the axle about which the axle turns for steering pur-

Fig. 45. Complete Front Axle Showing Steering Heads and Tie-Bar.

poses, although this construction is sometimes used; but generally each end of the axle is provided with a steering head into which a vertical spindle or neck is journaled, which neck carries the axis of the corresponding front wheel. To this neck is attached one or more steering arms for controlling the direction of the neck; and that the opposite wheels may be steered in unison, an arm on one side is connected with a corresponding arm on the opposite side by a tie-bar parallel to the front axle.

It is readily seen that in turning a corner both front wheels should be so turned that each will describe an arc concentric with the arc of the other, for if both arcs are not concentric, one wheel or other will be forced to slip sidewise to a greater or less extent, with the result that the tires will be worn and the steering will sometimes be controlled by one and sometimes by the other wheel, with consequent greater skidding and a very disconcerting eccentricity in the matter of steering. The same result is found in driving straight ahead if the steering wheels are not parallel to each other as they should be.

To insure that the steering wheels describe concentric arcs, the steering arms are projected either backward and inward from the steering neck or forward and outward, and the tie-bar is made of suitable length to hold the wheels parallel for straight ahead driving. This arrangement insures that the inner wheel on a turn will be steered at a greater angle from the center line of the vehicle than the outer wheel, and will describe an arc of a circle of shorter radius than the outer wheel.

Fig. 46. Front Axle with Lemoine or L Head.

It is quite evident that both wheels should steer around a common center and that the radius for one wheel in one case must be the width of the vehicle, usually about 5 feet, greater than for the other wheel. The proper angle for these steering arms depends upon the distance between the axles and the distance between the steering head center lines, and is found approximately by drawing a line through the steering head center to the middle of the rear axle.

Steering Heads. Steering heads are of several varieties according to the ideas of the designer. The simplest form is an L-shaped forging welded to the end of the straight front axle, the other member of the L projecting upward or downward, and in either event bored to receive the steering spindle. This is quite frequently termed the Lemoine type. A second form provides the axle with a T head, the extremities of the T being turned at right

angles, so as to form lugs through which the steering pivot pin passes. This also passes through the steering neck fitted between the lugs. This form is commonly termed the Elliott type. Recognizing the advantage of having the steering pivot as close to the spokes as possible, several makers made these projecting lugs very long, and in place of the vertical neck a curved C-shaped neck was provided carrying the spindle at its center, while at its ends short pivots or screws attached it to the lugs mentioned. This arrangement permits the use of a long wheel spindle and although slightly more expensive to build, and not quite so rigid as the other types, was used because of its merit by Haynes for a number of years.

In any steering device, the object is to have the steering pivot close to the wheel, so that the leverage of the wheel is extremely small, on which account obstacles do not have much tendency to deflect the course of the wheel. Any one who has watched the long pole of a horse wagon sway violently as the front wheels strike an obstacle, can realize how impossible it would be to control a motor vehicle by the arm of an operator unless a considerable mechanical advantage is gained in some manner, and placing the steering centers nearly or quite in the plane of the wheel, secures this advantage to a more or less complete extent.

Some vehicles are equipped with hubs of such size that the steering pivot may be placed exactly in the plane of the wheel, the wheel bearings being of larger diameter than the length of the steering pivot. Other vehicles use forks astride the wheel with the steering pivot over the wheel as in cycle construction. Both of these methods remove all leverage from the wheel, so that there is no tendency to deflect to one side or the other when it strikes an obstacle; but the large hub is objectionable and the long fork with the long framework necessary to get above the wheel is both costly and weak. The advantages of these constructions can practically be secured without additional cost or disadvantage by inclining the steering pivot so that the steering pivot center line strikes the ground at the same point as does the wheel. This construction is used on a number of vehicles at present and its merits will eventually force it to be used by all.

A few vehicles have been steered by the single kingbolt and fifth-wheel arrangement used on horse vehicles, in connection with a worm and segment for turning the axle about this pivot. This form is common in vehicles which both drive and steer by the front wheels, and is quite practical if means for steering by the power of the motor is provided. In order that the worm may have the power required it is of slow pitch and needs many revolutions to effect the desired steering, which rapid movement is not easily made by the operator. A device is easily provided, however, so that the motion of the motor drives the worm in either direction at will and accomplishes the desired result.

A double form mounts both front and rear axles on fifth wheels and swings them in opposite directions, thus steering both ends of the vehicle.

Front axles are usually solid, although sometimes made tubular for the purpose of saving weight. A single tie-bar between the steering arms is commonly used, but for the purposes of safety double ones are sometimes provided.

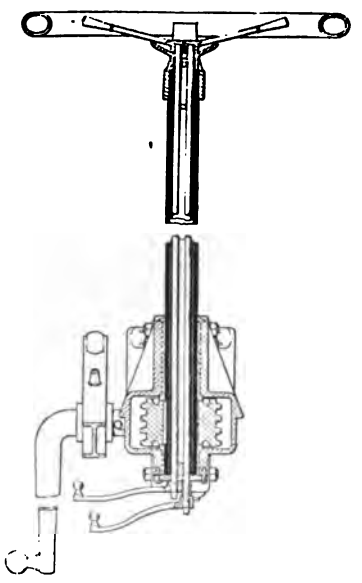


Fig. 47. Steering Wheel.

Control. In order that the front wheels may be controlled by the operator a number of means are used, the most common of which is known as wheel steering. This consists of a rotatable post fitted with a wheel at its top end and with a crank, pinion, or worm at its lower end. Where the crank is used a connecting rod connects the outer end of the crank with one of the steering arms which project from the steering head. Turning the wheel to one side a quarter turn throws the steering wheels to their limit in one direction from the center position, and a similar opposite turn throws them in the opposite direction. As commonly arranged, the post is turned in the

same direction as are the steering necks, so that the rear of the steering wheel moves in the same direction as the rear of the front wheels of the vehicle. In the earlier forms the steering post was vertical, but it is now considered advisable to incline the post backward at the top so that the operator's seat need not be so nearly over the front axle. The front end of many vehicles is

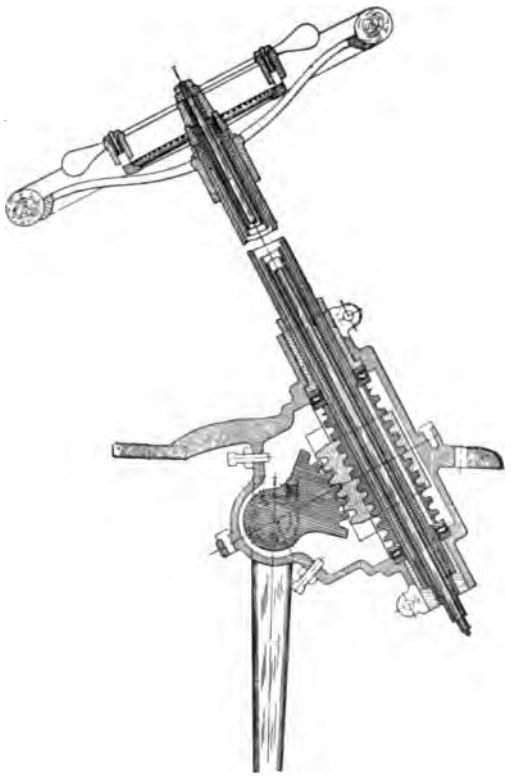


Fig. 48. Steering Wheel Showing Throttle and Spark Levers.

now utilized for the motor and as the wheels are steered, the front of the vehicle moves to one side or the other in a manner not found in horse vehicles and not conducive to comfortable riding. This objectionable feature is not found farther back, on which account the passengers are usually carried nearer to the rear axle. In some vehicles, the vertical post is equipped with a tiller or rearwardly projecting lever. This was formerly much

used on light vehicles and is a simple, natural method of steering, but not so satisfactory as other methods.

In other instances, the vertical post stands at the center of the operator's seat or at one side thereof, while the steering lever projects across the vehicle in front of the operator. This gives a powerful method of steering and is preferred by many to the tiller steering.

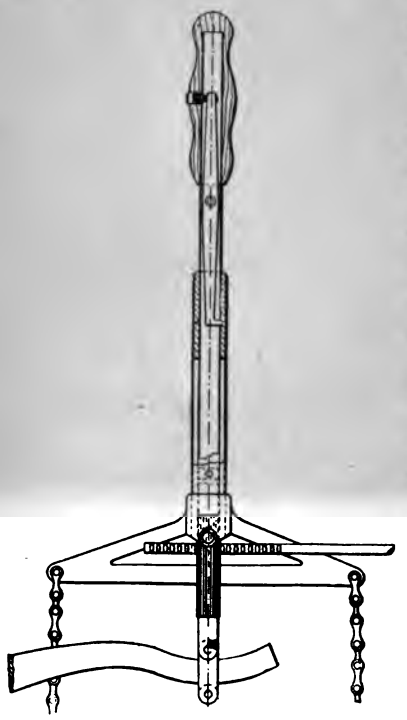
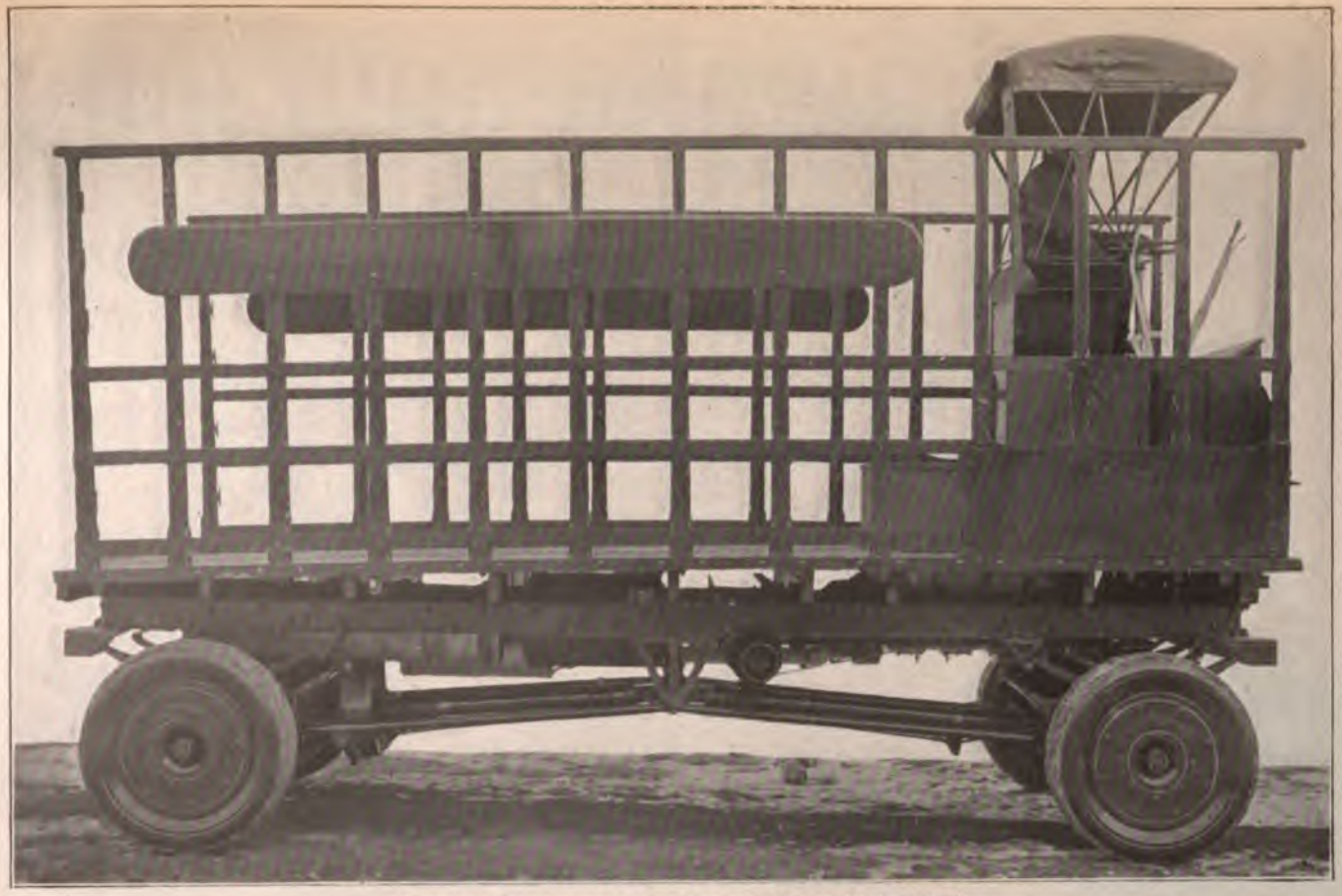


Fig. 49. Duryea Controlling Lever.

Swinging the lever sidewise pulls the chains and steers the wheel. Sliding the handle up or down shifts the lever setting either the high or low clutch. Twisting the handle shifts the rack which controls the throttle.

In order to get still greater power, double levers or handle bars have been used, but the preferred method is the wheel operated by both hands in connection with the worm or pinion at the bottom, by which arrangement the rotation of the post is not confined to a half revolution but is usually arranged to make nearly two revolutions and in some cases more, in order to turn the steering wheels through their extreme movement. It will be understood that the pinion meshes into a sliding rack attached to the proper end of the connecting rod, and that the amount of movement of the front wheels depends upon the diameter of the pinion.

When a worm is used the arrangement is slightly more complex, there being usually a segment of a gear adapted to mesh into the worm, so that a quarter revolution around the center of the gear is produced by the two or more turns of the steering post. Attached to this segment is an arm connected usually by ball and socket joint to the connecting rod. The advantage of this construction is that the worm locks the front wheels of the vehicle in position, against deflection



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by obstacles or causes other than the will of the operator. This arrangement is known as lock steering and is preferred by some. The free steering is the more common form, however.

A further form of steering employs a vertical lever carried by a horizontal pivot at the center of the seat near the front, and arranged to swing sidewise for steering purposes. This lever is between the passengers, does not interfere with mounting or dismounting, is in position to be operated by either passenger, and is much liked by those who have used it as well as other methods. Being patented, it is employed on one make of vehicles only.

Brakes. Second only to ability to go is the power to stop, on which account the brakes are most important. A wide variety of these have been used in the past but practically all have been abandoned excepting band brakes. A tire brake consisting of a shoe bearing against the tire of the wheel is considered detrimental to the tires and does not hold well on wet rubber. Band brakes are applied to the countershaft, to the rear sprocket, to the large gears of the balance gear and to the hubs of the wheels. They are of two varieties,—internal or expanding bands, and external or contracting bands. In the earlier form the external band was commonly used, one end being fixed to the frame of the vehicle, while the other was attached to the operating lever. Application brought the loose end in contact with the revolving drum which caused the band to tend to wind itself around the drum, forming a very effective brake without requiring a great amount of power for operation. This form was faulty when running backward because the friction of the loose end of the band against the drum tended to release the band, with the result that brakes of this kind hold well in one direction but not in the other.

Most forms of band brakes now are attached at the middle of the band, leaving both ends for operation. This insures that no matter which way the vehicle is moving, the brake is equally powerful. In one or more forms the band is provided with two points of support, one of which takes the strain in a forward direction, the other in a reverse; and since both ends are equally operated upon, this form of brake is particularly powerful and requires but the slightest effort on the part of the operator, being practically self applying. On the heavier vehicles internal and external bands

are sometimes applied to the same drum affixed to the hubs. This utilizes double the surface and gives enormous braking power. Many varieties of arrangement are found, but the general principle is the same. Brakes are usually operated by foot levers, but many vehicles have also a hand lever.

Two methods of braking are considered good practice, and most vehicles can be stopped by throttling the engine or applying the proper clutch, so that even if only one brake is used, a second means of control is always present. Some makers believe it is better to fit one brake only, in order that the user, by using it daily, may not only know its condition, but may be trained to use

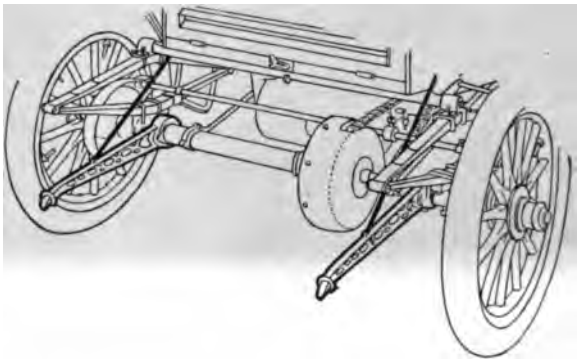

Fig. 50. Drop Brake.

it instantly and automatically, because it has been found that in emergencies the operator forgets special features like an emergency brake, and fails to use them even though he had depended upon them to the neglect of the condition of the more commonly used brake.

To prevent movement backward in case of failure of the brakes, a sprag is commonly used. This is hinged to the rear axle of the vehicle and is let down at the bottom of the hill so that it drags, forming a pawl, which at the first backward movement of the vehicle digs into the ground, effectually stopping movement backward. Some vehicles have the wheels provided with ratchet teeth and a pawl to engage them in the same manner. Others depend on brakes only, but in order that the vehicle may be left

standing on a hill, provide the brake levers with ratchet and pawl to hold them when set.

WHEELS

There are few more important parts in a motor vehicle than the wheels. These are sometimes made of steel, much like bicycle wheels, but the earlier forms were made too light, on which account this style of wheel has been largely condemned. The same fact applies to wooden wheels as commonly used on carriages, with the result that the accepted form to-day is the artillery wheel, a construction having wooden felly and wooden spokes with large butts. These butts join each other forming a complete circle of wood at the hub and are gripped between flanges of metal bolted together through the wood. Any loosening of the spokes at the hub is taken up by tightening the bolts. To the wooden felly is attached the metal rim which engages the pneumatic or solid rubber tire. Some wheels are in use having steel spokes and some experiments have been made with springs instead of spokes in the attempt to gain elasticity in the wheel instead of at the tire. The common wheel, however, is the artillery form described.

It is a noticeable feature of motor vehicle wheels that they are much smaller than the wheels of horse vehicles, although the loads carried are decidedly larger. The reason for this is three-fold. Pneumatic tires are costly, so the vehicle maker to save first cost, uses a small wheel with consequently small and cheap tires, and the buyer having no experience assumes that this must be best, after which the maker excuses himself by saying: "The public wants it." Small wheels are doubtless responsible largely for the great tire and mechanical repairs frequently connected with motor vehicles, and also with the lack of practicability on bad roads, in deep snow, and similar conditions, successfully negotiated by horse vehicles. The second reason for small wheels is the fact that the motor runs more rapidly than the wheels, which necessitates gearing, and large wheels require a greater difference in gear ratios than do small ones, thus increasing the difficulty of the builder. A third reason for small wheels is their greater strength, but it seems wiser to use large wheels and decrease the weight of the

parts to be carried, particularly over the rough roads found in most parts of America.

Tires. Since motor vehicles depend upon the wheels for propulsion, tires having great traction are necessary, particularly if a large proportion of the load is carried on the front wheels, which must be pushed by the rear ones. On this account rubber tires are practically necessary, because steel tires slip on every bit of ice, on iron rails, and even on hard pavements unless caused to grip by spikes or similar projections, which are both rough and noisy. On some vehicles blocks of wood, presenting the end of the grain to the street, are used instead of tires and are found more durable and less expensive than rubber and less noisy than metal, while giving good traction. For trucks, such tires seem well adapted. Wide heavy tires of solid rubber are also used on heavy vehicles, but the pneumatic tire from $2\frac{1}{2}$ to 5 inches in diameter is the prevailing form. These not only give traction but smooth the road very perceptibly, and are therefore well adapted to high speed. Although many other styles are constantly being tried, such as various forms of arched or cushioned tires, also tires having steel springs for resiliency, the pneumatic tire is almost universal.

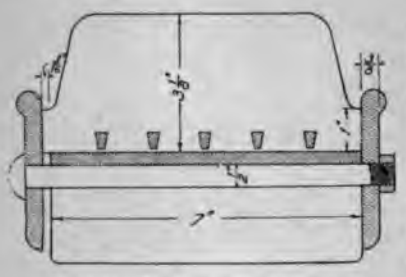

Fig. 51. Solid Rubber Tire for Heavy Vehicle.

This was formerly most common in the single tube shape, but of later years the detachable tire, consisting of an outer shoe or casing with a removable air tube, has become the favorite. Metal rims are nowadays provided with one side removable, which permits the tire to slip off easily, after which the air tube can be repaired or a patch laid on the inner side of the casing. Three common forms of tires are in use at present.

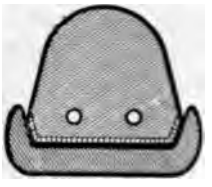

Fig. 52. Solid Rubber Tire for Light Vehicle.

The Clincher tire is so called because as first constructed, its edges were provided with hooks or clinchers, which engaged

similar hooks along the edge of the rim. As now constructed these are practically abutments resting against the upturned edges of the rim, the tire being held down in the rim by its constrictive fabric, which causes it when inflated to shorten in length and grip the rim forcibly. Clincher tires are sometimes held in place more positively by large-headed bolts, which clamp the edges of the casing between the heads and the sides of the rim and prevent the tire from lifting and blowing out of the rim when turning corners at speed, or when partly deflated.

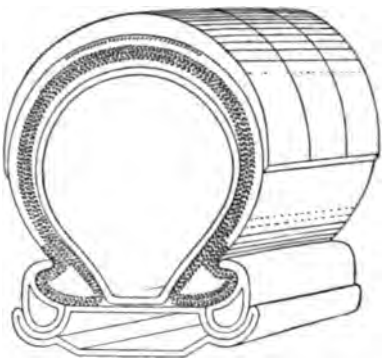

Fig. 53. Clincher Tire.

The wired tire has an endless wire fitted in each edge. This wire is just large enough to pass over the base of the rim and cannot pass over the flange or side when in place. In this form the wire performs the duty of holding the tire to the rim, so that the fabric is called upon only to retain the air pressure within the tire and may therefore be less strained than in the constrictive form where it must both hold the air and also the tire itself, thus performing a double duty. A third form has its edges clamped along the sides of the rim by mechanical means. This is a most positive fastening, effectually preventing creeping, rolling, or blowing off, but it is not so quickly removed for repairs as is the wired tire with removable flange to the rim.

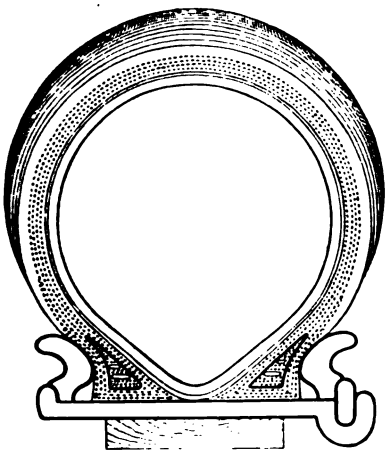

Fig. 54. Wired Tire.

When deflated the removable ring is pushed inward, the bead removed from its groove, after which the removable ring and tire slip off freely.

With tires as with wheels, the size is important. The strength of rubber and fabric is quite limited and a surface suffi-

ciently large to support the load without damage to the rubber, must be provided if the tire is to be durable. The constant bending of the tire in the performance of its duty, wears out both fabric and rubber resulting in bursts and blow-outs, while danger of puncture is always present. These objections are best overcome by the use of tires of small diameter in cross section on wheels of large diameter. In this form the contact on the ground is quite long, thus securing a large supporting surface; the wheel revolves less times per mile, thus bending the tire less often, as well as allowing the heat caused by the bending of the tire to dissipate; and finally, the narrow tire is less likely to puncture, for it does not pass over so wide an area and therefore encounters proportionately a less number of causes of puncture. Further, it meets less resistance from mud, sand and gravel, skids less, and therefore is less damaged than a tire which slips and skids more frequently, because it is abuse rather than use which damages any construction. The tire of large section on a small wheel has a bearing more nearly circular on the ground and slides like a snow shoe easily in any direction and thus contributes to skidding, whereas the large wheel with narrow tire is more like a sleigh runner and less likely to skid sidewise. The large wheel rolls out of depressions easily instead of slipping around in them, and it is believed by many that skidding and rapid wear are largely found under the same conditions.

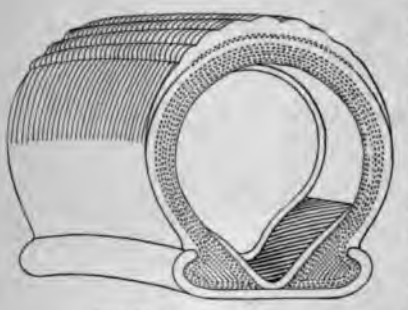

Fig. 55. "G. & J." Tire.

A sudden application of the brake will frequently start skidding, and this is known to conduce to tire destruction. The same remark applies to sudden or jerky applications of the power. On this account the operator should cultivate handling the vehicle smoothly without jerks or abuse. In case of skidding, minimize the trouble by easing the brake or partly shutting off the power, and at the same time swinging the steering wheels, so as to carry the front end to the same side as the rear. Jamming on the brake

or shutting off the power suddenly is liable to make the matter worse.

IGNITION.

One of the most important features of the gas engine is the ignition. It is also the most delicate, and therefore the first place to look for trouble when things go wrong. Present day autos make use of one of three systems of ignition and some are fitted with two forms so as to have reserve if one form fails. In America the make and break spark was the earliest form and has been continued by one maker until the present. This form, also called the wipe, touch, contact or kiss spark, employs two electrodes within the cylinder, one of which is usually insulated in a fixed position, while the other is not insulated, but is movable and arranged to come in contact with the fixed electrode and be separated at the moment the spark is required. In some cases the movable electrode is insulated instead, and in still other cases both electrodes are insulated.

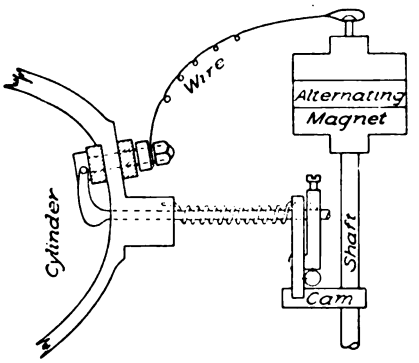

Fig. 56. Make and Break Ignition.

The electric circuit from a battery or other source passes directly through these electrodes, but in order that the spark may be rendered more intense than would otherwise result, it is customary to introduce a simple coil into the circuit, except in such cases as do not need this because of the nature of the generator. The low tension alternating magneto, for example, needs no coil, the windings and core of the armature serving this purpose perfectly. A shunt-wound dynamo will also give a large spark without the use of a coil if the contact is but instantaneous. The coil used with a half dozen cells or with direct-current magnetos or dynamos is identical with that used for lighting gas in dwellings. It consists of a core of soft iron wire, 5 to 8 inches long by about 1 inch in diameter, wrapped with four to ten layers of insulated copper wire $\frac{1}{16}$ inch diameter. When a current passes through this coil, the core is saturated with magnetism, thus storing, as it were, the energy of the current. When the circuit is broken at the electrodes

by separating them, the magnetism in discharging from the core induces a very intense current in the coil, which jumps the gap between the electrodes, making a spark so intensely hot that even heavy cylinder oil is varporized and any reasonably explosive mixture is ignited with certainty.

The movable electrode is operated by any suitable mechanism, which differs in different designs, but it is a common practice to bring the points together by a strong spring and to separate them by a blow as from a hammer. The coil used must both charge and discharge quickly in order to be suited to high speed work, and since the spark is caused by the discharge, the points must be separated far enough (nearly $\frac{1}{8}$ inch), to give ample room for the spark before the strength of the discharge has been spent, so that in this, as in the vibrator of the ordinary jump spark coil, a sharp, quick break is an essential feature. The moving parts must also be light in order that they may move quickly. The merits of this system have compelled recognition from the best makers and it now seems likely to supersede the jump spark on high grade vehicles.

In France the jump spark was used as early as 1862 by Lenoir, and later by Benz in Germany. It was brought to its most successful form on high speed motors by DeDion and Bouton about 1896 and its success on the many little tricycles turned out by this concern gave it an impetus into public favor, which it has largely since retained. In this system the two electrodes are both fixed, generally in the form of a plug which may be screwed into the wall of the cylinder. Usually one electrode only is insulated, but both are insulated in some cases and connected to the two high tension terminals of the jump spark coil or transformer. This coil is quite complicated and consists of a primary winding, forming part of a primary circuit—the equivalent of the circuit employed on the make and break system—a condenser connected across the primary circuit on opposite sides of the circuit breaker, and a secondary coil

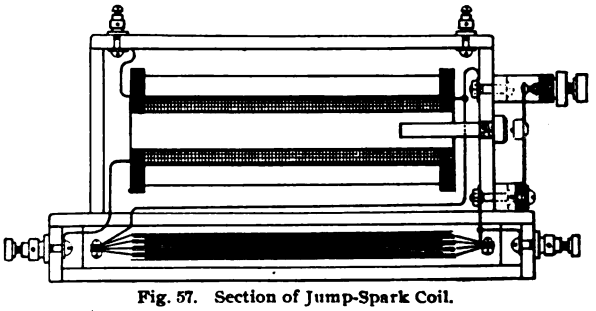

Fig. 57. Section of Jump-Spark Coil.

parallel to the primary, but much longer and of finer wire. The theory of this coil is that when a current is passed through a wire it will induce a current in another wire parallel to the first. When the circuit is broken, the core of the coil being saturated and discharging, as in the primary coil, induces a very strong electric impulse in the long secondary coil, with the result that a spark will jump a considerable gap between the electrodes to which the terminals of the secondary coil are connected. Because of this ability to jump, the system takes its name. In the primary circuit of both systems, the induced current tends to jump where the circuit is broken, but in the secondary circuit the induced current must jump the permanent gap because the terminals do not move.

In order to avoid the large spark at the breaker or vibrator in the primary circuit, a condenser consisting of many layers of tin foil insulated from each other by waxed paper, is arranged with alternate sheets connected to the terminals of the primary circuit on opposite sides of the circuit breaker. This device in effect prevents the discharge of the core from expending itself by producing a current in the primary circuit, and therefore increases or condenses the spark in the secondary circuit.

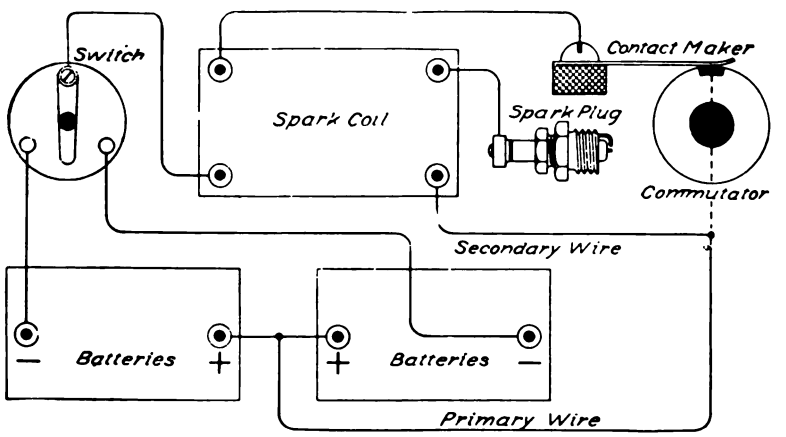

Fig. 58. Wiring Diagram of Jump-Spark Ignition.

In the simplest forms of jump spark ignition, the primary circuit breaker is operated by the mechanism of the engine, which causes the primary circuit to be broken when the spark is desired, just as in the make and break system. Since, however, better re-

sults are obtained by closing and breaking this circuit at a certain rate of speed, than at other rates, it is now most common to employ vibrator coils which have a spring arranged to close the circuit and employ the magnetism of the coil to attract the spring, when the core is saturated, and thus automatically break the circuit, resulting in a continuous vibration or buzzing with an accompanying stream of sparks. With this arrangement it is necessary to break the primary circuit in order to stop the sparks when not wanted, and to this end a timer is operated by the engine instead of the mechanical breaker. By means of this timer the current is connected at the proper time and the vibrator produces one or more sparks, one only at high speeds and several at very low speeds, as when starting. This timer is usually adjustable so that the circuit may be connected earlier or later as compared with the movement of the engine by which arrangement it is possible to produce the spark as desired, either after the piston has passed the dead center, or more or less before the dead center, in some cases 45 degrees ahead.

Fig. 59. Jump-Spark Coil.

The object of this advancement is two-fold. The jump spark is so small that the ignition of the explosive charge begins slowly. Second, the time required by the vibrator after the primary circuit is connected, is dependent upon the adjustment of the vibrator but may be such part of a second (usually .004 to .005) that the crank shaft will have moved 5, 10 or even more degrees of angularity before the spark takes place. This lag is particularly noticeable when the vibrator has just broken connection as the timer made connection, the result being that the spark cannot occur until the vibrator spring has made one movement and swung back into contact long enough to charge the coil.

This condition frequently exists with the result that ignition takes place at various times instead of at a fixed point, as with the make and break, and the position of the timer does not represent the average ignition position but rather the advanced position with average cases much behind and extreme cases still more

APPERSON 100 HORSE-POWER RUNABOUT, PRICE $11,500
The most expensive automobile of domestic manufacture shown at the Chicago Automobile Show, 1906

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so. Recognizing this effect, jump spark users are, to some extent, employing a single coil on multiple cylinder engines and distributing the secondary spark from one plug to the next by a well insulated commutator or distributor, so that the average position of ignition may be the same on all cylinders. If separate coils with separate vibrators are used, the difference in the vibrators causes a different average position of ignition and since the multiple point timer cannot be adjusted for one cylinder independent of another, the result is a slight difference in the strength of operation of the different cylinders.

Fig. 60.
Jump Spark Plug.

Since the secondary or high tension current of the jump spark system is of sufficiently high voltage (10,000 to 25,000) to jump the gap between the electrodes while the charge is under compression, it will jump a very large gap in the open air, and must therefore be very carefully insulated. Rubber covered wire $\frac{1}{2}$ inch or more in diameter is commonly used, the wire itself being very small. The plugs are usually of glazed porcelain or of tightly rolled mica or in some instances, of lava or other heat resisting materials. The gap between the electrodes or spark points is usually $\frac{1}{32}$ inch, or slightly more, and a spark to successfully ignite, under the influence of the resistance of the compressed charge, should have sufficient energy to jump $\frac{3}{8}$ or $\frac{1}{2}$ inch in the open air. A leakage of electricity from the high tension circuit can usually be seen in the dark by a slightly luminous brush-like discharge, and indicates a point where the insulation should be improved if the best results are desired.

A third system, which has attained some prominence recently, is the magnetic make and break, commonly called the magnetic plug. In this device the magnetism of the primary coil or of an auxiliary primary coil is used to separate the movable electrode from the fixed electrode instead of the separation being made by mechanical means. A timer is necessary in the circuit for the circuit is commonly closed and must be broken by the timer to prevent a continuous succession of sparks. The fault of this device

is that it is not well adapted to currents of varying strength, as for example, the current from a generator driven by the engine; because in starting, the engine cannot be turned fast enough to produce a strong current and the magnetic plug will not operate, or if adjusted to operate on a weak current, it operates continuously on a small saturation of its magnet and breaks the circuit before the core is properly saturated as is required for large spark. To overcome these defects, a two circuit device has been used, both primmary, and not complicated. One circuit operates the make and break while the other is a sparking circuit pure and simple. The magnetic plug is believed to combine to a large degree, the good features of both the make and break and jump systems and with suitable development will doubtless have a large future.

Fig. 61. Magnetic Spark Plug.

The hot tube ignition used by Daimler and others until the beginning of this century is now seldom found.

Galvanic Cells. The earliest source of current was galvanic cells employing a liquid electrolyte. These were sloppy, short lived and very unpleasant to handle, because of the nature of the electrolyte, which was either sulphuric acid, caustic soda, sal ammoniac, or something of this nature. Such batteries have been replaced by dry cells packed solid and simply moistened with a sal ammoniac solution. These are not likely to leak even when placed on their sides because of the small proportion of liquid contained by them. They are cheap in price and because of their use in telephone service, are purchasable almost everywhere. They deliver their output under a tension of one to one and one-half volts and therefore require a less number in series than most wet cells. The ordinary make and break coil is designed to operate with from 6 to 10 volts and 2 or more amperes, although very satisfactory results can be obtained with much less. The jump coil is usually wound for four to eight volts and gives best results if the amperage is quite large. Four to six cells in series is the customary battery,

and good practice makes use of two or more series alternately until all are perceptibly weakened, after which two series are connected in parallel or multiple which doubles the strength (amperage), while maintaining the proper voltage. As the voltage of the cells decreases, connecting an additional cell in series is advisable.

Some users prefer storage cells known as accumulators or secondary batteries. These cells deliver two volts each, and since the internal resistance is low, they will deliver a large quantity of current and thus make a strong spark. They are prepared in small sets suitable for ignition purposes, giving four to ten volts, and although heavy, are quite reliable. Their first cost is greater than dry cells and the cost of recharging is frequently as much as a new set of dry cells. They are probably most satisfactory when used in connection with a direct current magneto or dynamo, by which they are kept fully charged and able to give a strong spark.

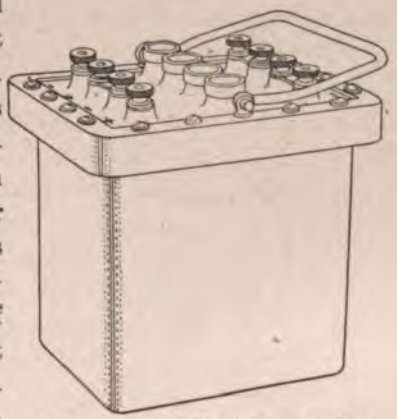

Fig. 62. Accumulator for Gas Engine Ignition.

Mechanical Generators. An early form of mechanical generator was a small shunt-wound dynamo. These are used to a considerable extent and not only give large sparks for both the jump and make and break systems, but also serve to charge batteries, light electric lamps, operate magnetic clutches and even operate magnetic horns.

Fig. 63. Direct-Current Magneto.

The most common form of mechanical generator is the direct-current magneto, which differs from the dynamo in that the field is composed of permanent magnets. These generate current at lower speeds than the dynamo and the current does not increase in quantity with the speed to so large an extent, on which account it is better adapted to the varying conditions of auto work.

It is customary to drive these direct-current generators by friction pulley in contact with the fly-wheel, and some form of governor is provided to withdraw the pulley from contact and thus prevent the generator being driven at excessive speeds, and yet be driven by the small pulley at a speed fast enough to spark when the engine is running slowly. It is quite common to use these devices for starting the engine, but in many cases a battery of dry cells is provided which makes starting somewhat easier.

The alternating magneto will produce two sparks or electrical impulses at each revolution of the armature, and in order that these may occur at the proper time, it is positively driven by gears. This form has no brushes and only one contact from which the live wire is carried. The discharge of the armature serves the same purpose as a spark coil, so no spark coil need be used. As ordinarily made, these are about twice as heavy as the direct-current magneto and will give a spark at as low as 50 or 75 revolutions per minute, whereas the direct-current magneto requires five times this speed to generate a spark sufficiently strong for ignition. Of course, neither magneto will spark properly at such speeds, the alternator usually requiring several hundred revolutions, while the direct-current device or the dynamo are usually driven above 1000.

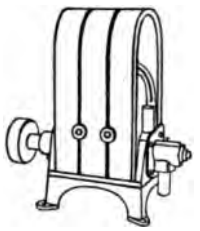

Fig. 64. Alternating Current Magneto.

In case of trouble the brushes or contact points are usually at fault. The contact surfaces will frequently be found dirty and glazed in a manner to prevent the passage of current. Sometimes a bit of iron attracted by the magnetism forms a short circuit across some insulated parts. The bearings should be carefully watched, for if much worn the armature will strike and reduce the speed, or if dry, the friction of the bearings will be greater than that of the driving pulley and the speed will be too low for regular ignition. If the pulley surface is dry, apply belt dressing or a trace of heavy oil; but if greasy, apply powdered common chalk. Resin is sometimes used, but if the fly-wheel surface is hot it is not satisfactory, because it is oily when hot and increases the slipping. These remarks also apply to friction driving gears.

PUMPS.

Pumps are usually one of three varieties, centrifugal, vane, or gear, although reciprocating plunger pumps are occasionally used.

The centrifugal pump is usually 5 or 6 inches in diameter by 1 inch thick, with a revolving vane driven by a shaft which projects through a stuffing box forming one end of the axis of the pump. The water is admitted at a central opening on the opposite side of the case and leaves the case through a tangential opening on the edge. These pumps are not easily clogged, have no parts to wear or be noisy, employ no valves, and do not impede the natural circulation of the water if for any reason they cease running. They are quite usually driven by friction pulley and are generally speeded to 300 revolutions per minute or faster.

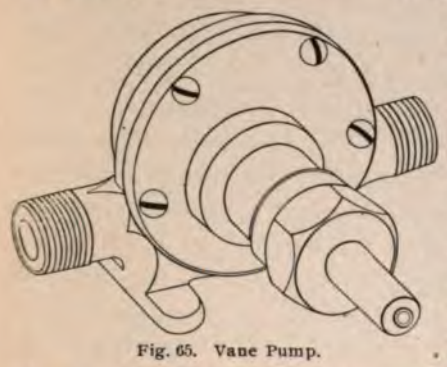

Fig. 65. Vane Pump.

The vane pump is somewhat smaller in diameter but of greater thickness and has the casing eccentric with respect to the shaft. The inner end of the shaft is enlarged concentrically to meet the closest inner surface of the casing, and a slide or vane is forced by the revolution of the shaft alternately back and forth through this enlarged end. This slide is frequently divided at its center and fitted with a spring, which keeps the ends in contact with the inner circumference of the case at all times. The inlet and outlet are tangentially placed on either side the contact point of the enlarged shaft end. The vane ends wear rapidly if the water contains grit, and small obstacles are likely to do damage. This form of pump is usually driven by gears or attached directly to the cam shaft or similar part of the motor.

Fig. 66. Gear Pump.

The gear pump consists of two gears of coarse pitch, meshing together and revolving in a figure -8- shaped case, the inlet being on one side of the center, the outlet on the other. The liquid is carried by the tooth spaces around the ends of the 8 but cannot return between the gears because crowded out of the spaces by the

meshing of the teeth. This pump has no valves but like the vane pump, is liable to damage if foreign matter is permitted to enter, and it is of small capacity in proportion to its size. These pump shafts are fitted with stuffing boxes to prevent leakage of water around the shaft. Prepared packings are usually supplied for these boxes, but candle wick filled with tallow or other heavy grease is quite commonly used.

Reciprocating pumps employing piston and check valves are sometimes used but not frequently, although common in launches.

Failure of the pump to work is usually manifested by rapid boiling of the water, smoking of the lubricating oil, and in extreme cases, by loss of power, premature ignition, with pounding, and the symptom of stiffness in the engine when turned by the starting crank. An air or steam trap or pocket is often responsible. Drain the system and refill taking care to get out all air. If clogged by solid material the pump must be opened although turning backwards may relieve it temporarily.

AIR FANS.

For air circulation the ordinary screw-blade fan is most common. This is seldom constructed with less than four blades and generally, in order that it may not be of great thickness in proportion to its diameter, it has eight to twelve or even more blades. It is usually mounted on ball bearings commonly run by V or round belts, although flat belts and spur gears are sometimes used.

Next in frequency of use is the practice of making the spokes of the fly-wheel serve as fan blades and thus avoid the fan with its extra parts, high speed, added bearings and extra oil cups. The use of a centrifugal fan or blower has been attended with good results and is advisable where much pressure is preferred rather than large volume of air. In some instances the energy of the exhaust has been used to induce a current of air and cause this to assist the cooling without additional mechanical parts.

Both pump and fan troubles usually arise from failure to be driven, generally because of slipping of the belt or friction pulley, or because some obstacle impedes the movement of the pump or fan. Pumps sometimes cease to work because they fill with steam, which leaks back through the pump as fast as it is forced forward. The remedy is usually obvious and the trouble is noticed when symptoms of overheating in the engine appear.

BODIES.

The bodies of most autos have one common feature, i. e., the operator's seat. This was formerly placed well to the front, as in horse vehicles, but because of the sudden sidewise movement of the front end, due to steering, this seat was found more comfortable if placed further to the rear, and since many owners are also drivers of their own vehicles, the operator's seat is usually at mid-length of the vehicle. The motor, originally under the floor of the vehicle, is now quite commonly placed vertically in front and covered with a bonnet, which utilizes the available space in front of the operator. On this account additional seating room is secured at the rear, over and frequently behind the rear axle. In some vehicles, as in the Orient, and Adams-Farwell, the motor is at the extreme rear, near the rear axle, while the passengers are carried between the wheels as in the horse vehicle ; a sensible and practical arrangment.

The form of additional seats has been a matter of wide difference of opinion. Some early vehicles had a front seat facing rearward. Later the dos-a-dos was considerably used because it permitted an unbroken space, under both seats, for the mechanism. The dust and exhaust gases behind the vehicle would arise unpleasantly in the faces of the passengers and this rendered such seats unpopular. Rear seats oppositely facing were next tried and this form gave way to the "tonneau," having a seat on each rear corner much resembling two water barrels, from whence the name. A door between these seats, opening at the rear, completed this form, but the necessity of dismounting in the street when the vehicle stood alongside the curb, soon destroyed its popularity.

Side door rears with an occasionally a side door front now prevail. This is a much nearer approach to the common horse surrey, and it seems likely that the satisfaction found by horse users will be accepted by auto users and doors done away with except in the heavier and more elaborate vehicles.

Emergency Seats. For temporary increased seating capacity, emergency seats are quite common. The high cost of the auto as compared with horse vehicles makes it necessary that one vehicle should serve several purposes instead of there being provided a variety of vehicles. When the mechamism was carried at the rear, a front seat usually facing forward and arranged with folding foot

board and back was quite common, This was directly over the front axle, rode unpleasantly, required lap robs to protect ladies' and children's skirts from the wind, and exposed the passengers to dangers of collision and scary horses, as well as getting them in

Fig. 67. Arrangement of Extra Seat.

the way of the operator's vision. Seats facing the rear are still used in large tonneaus and serve well.

The folding rear has been recently introduced and converts the runabout into a surry in a practical, comfortable and inexpensive

Fig. 68. Folding Rear Seat Phaeton.

manner. Unlike a detachable tonneau, it is always present when wanted, and quickly closed when not wanted. It adds little extra weight, requires no mechanical work to open or close and bids fair to be a permanent device.

In some forms of vehicles notably cabs and broughams, intended to be driven by drivers for hire, the operator's seat is at the extreme front or at the extreme rear as in similar horse vehicles. It seems evident that similar requirements will largely dictate similar forms in autos as in horse vehicles, and mechanics will doubtless be able to accommodate the mechanism to the bodies without great deviation from those vehicle forms proved by years best suited to the needs of the public.

Tops. Auto tops are substantially the equivalent of those used on horse vehicles although generally larger and more strongly made. They are either single or double, of the folding or cape top variety, with occasionally a canopy top and quite frequently a standing top with curtains or with glass windows, forming a

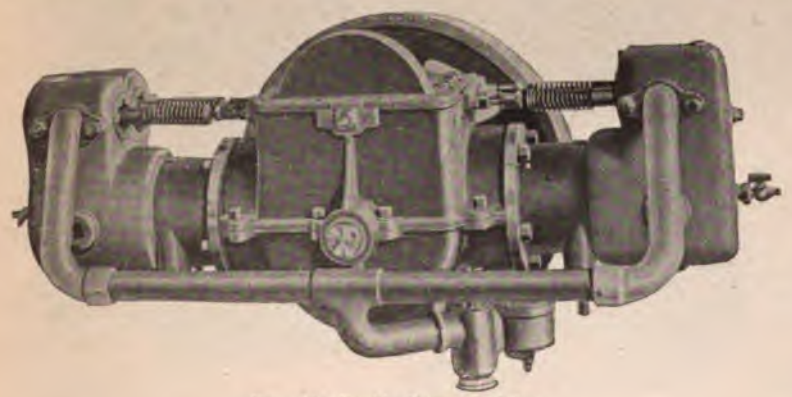

Fig. 69. Double Opposed Motor.

completely enclosed vehicle. High speeds in cold weather have made some form of protection desirable, so glass plates are fitted in front of the driver and are used either with or without the top as desired. They should be folding or removable because the air carried behind them is dust laden in dry weather and in rain or snow one can not well see through them.

Location of Mechanism. Several arrangements of mechanism are in use. In the earlier forms the motors were placed under the operator's seat because this was near to the driven axle and was the most available space unused by the passengers. As motors increased in size this space was not sufficient, so the body of the vehicle was extended backward, the full height of the seat, giving much additional room. Additional passengers were either placed

in front or on top of this rear extension, with the result that, as motors were made still larger, they were crowded down under the floor in a dark and inaccessible position as well as exposed to the mud and dust of the road. These faults compelled recognition, and, coupled with the unpleasant riding qualities of the front end, caused the motor to be placed at the front with the transmission gear and similar fittings under the floor as in common use at present. In a few instances designers were able to provide sufficient power in the space under the seat and thus avoided placing the motor in front, far removed from its point of application of power, and the success of such arrangement with the success of rear-

Fig. 70. Vertical Four-Cylinder Engine.

placed motors renders it likely that in the near future the motor at the rear will be considered, as it undoubtedly is, the best engineering practice.

Most designers began by using single-cylinder motors which were placed horizontally lengthwise of the vehicle, because this placing secures low center of gravity and least vibration. Increased power was secured by doubling the cylinders, but since a twin motor of the four-cycle type ignites in irregular sequence if the cranks are opposed, the double opposed motor became the accepted two-cylinder form. This ignites one cylinder each revolution instead of one and one-half revolution followed by one-half revolution apart, as in the twin-cylinder type.

Doubling the twin motor gave the common four-cylinder en-

gine, usually placed vertically, with crank shaft lengthwise the vehicle. The reason for this arrangement is that the width of an ordinary vehicle is not sufficient to place the motor crosswise, with crank shaft parallel to rear axle, as in the single and double cylinder arrangement. The triple cylinder motor is used by some makers who believe that it secures multiple cylinder results with the least complication and is therefore the most desirable form. Such engines, with cylinders of 5-inch bore, are placed crosswise of the vehicle as in the Duryea while four cylinders of nearly 4-inch bore are placed crosswise at the front in one or two air cooled

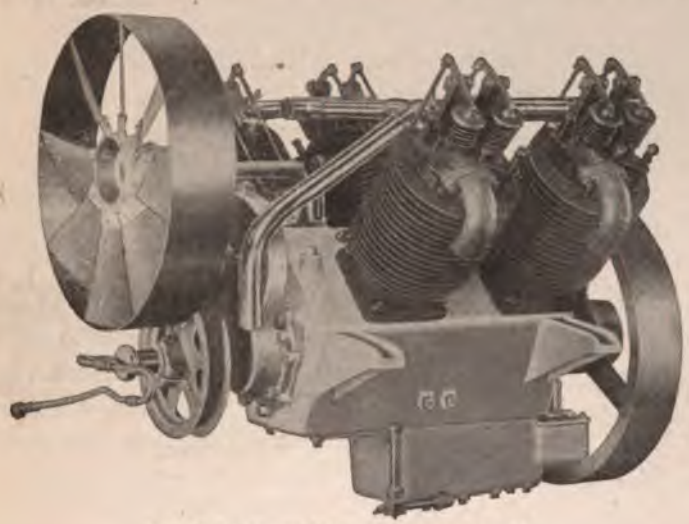

Fig. 71. Marmon Inclined-Cylinder Engine.

vehicles, as in the Marion. But the usual arrangement is lengthwise of the vehicle in vertical position when more than two cylinders are used. In the Marmon the cylinders are inclined two to each side about 30 degrees from a vertical position, while in the Duryea, the cylinders are inclined to the rear, 30 degrees from horizontal. In the Adams-Farwell, either three or five cylinders are used, equally spaced around a vertical axis and arranged to revolve in a horizontal plane. The weight of the cylinders avoids need for a fly wheel and their motion gives an efficient air cooling without fans or other mechanism.

In one or more instances the cylinders have been placed equally distant around their axis of revolution and parallel thereto,

which arrangement also secures steady rotation without a fly-wheel, and efficient air cooling. The auto is largely the sport of the wealthy and as is the case with all new things, is frequently provided, to the point of vulgarity, with various fittings and trimmings quite often made to sell rather than to use, and bought rather for ostentation than for any real service. A considerable business is done in these fittings, some of which are quite elaborate and expensive.

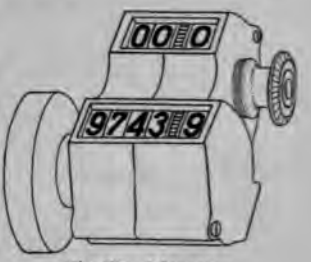

Fig. 72. Odometer.

FITTINGS.

Odometers are arranged with a single dial to give the total distance travelled or with a secondary dial to record the distance of each

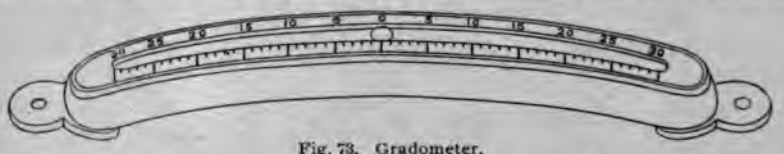
Fig. 73. Gradometer.

trip. Speed indicators show at a glance the speed at which the vehicle is traveling at any time, while clocks affixed to the dash board relieve the operator of the necessity of consulting his watch. Gradometers indicate the angle of the hill with more or less accuracy. Manometers tell the story of the water circulation. Voltmeters and ammeters advise concerning the electric circuit and various gauges and glasses show the action of the lubrication, the amount of fuel and water, and the air pressure in the air brake reservoir or gasolene tank as the case may be. Spark coils and acetylene generators, storage tanks and storage batteries are quite frequently in evidence while horns, gongs, or whistles complete the list. Some of the latter are numerous enough and properly toned and arranged to permit playing a tune. All are well in their place but add needlessly to an already

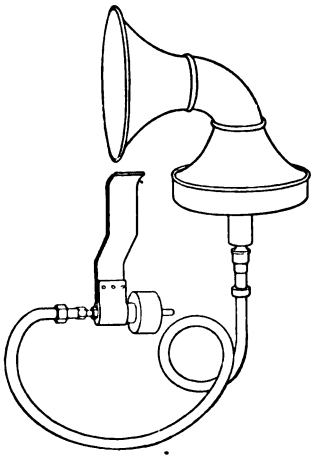
Fig. 74. Siren Horn.
A pulley running on the tire of the vehicle rapidly revolves a disk filled with holes. The result is a loud sound.

complicated vehicle and are not in accord with the simplicity which

Fig. 75. Three-Toned Horn.

must accompany an extended use of this valuable invention.

SHOCK ABSORBERS.

The high speeds frequently attained by motor vehicles greatly magnify inequalities of the road surface, with the result that the springs are violently compressed and rebound disagreeably, sometimes breaking. To prevent this, friction surfaces have been applied, which, while they permit yielding, dampen or deaden the spring action and render the vehicle more comfortable. Some forms of these employ pistons with valves or passages which permit free movement in one direction, but not in the other. It is urged against this that at high speed the second inequality is met before the springs have recovered their position, so they are unable to perform their duty.

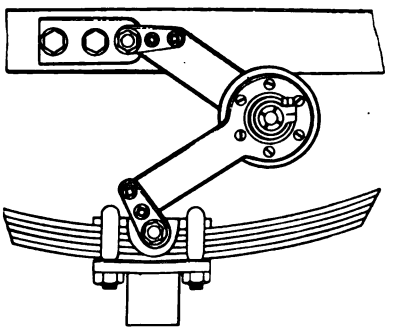

Fig. 76. Shock Absorber.

Springs. The comfort and durability of the vehicle depends largely upon the springs, although following cycle practice, many constructors have depended upon tires for this service. As in carriages, three forms of springs are quite common with a number of less used forms. The full elliptic has always had recognition and is a serviceable spring, but does not offer the rigidity sidewise that the half elliptic secures. It is quite essential that ther car axle at its sprocket should remain in line with the body or frame which carries the front sprocket, as otherwise the chain may jump off. The full elliptic requires the use of reaches or radius rods to hold the axle in position, but the semi-elliptic is usually fastened to the framework at one end, while the other end is carried by a swinging shackle. Side springs fastened to the body at their centers, and to the axle at their ends, have been much used on cheap constructions, and although not the best form, have given good service.

Spirial springs are sometimes used, principally as an accessory, to modify the action of the main spring or to assist it to carry the load. The high speeds frequently attained by autos, together with the small wheels used, demand exceptionally good spring suspension, which has heretofore been neglected, but is receiving more attention at present. Rubber buffers have been frequently used to prevent overloaded springs, and many a bent or broken axle has been due to improper spring design. In case of a broken spring it is usually possible to fill in the space with a block of wood which will permit the vehicle to be used.

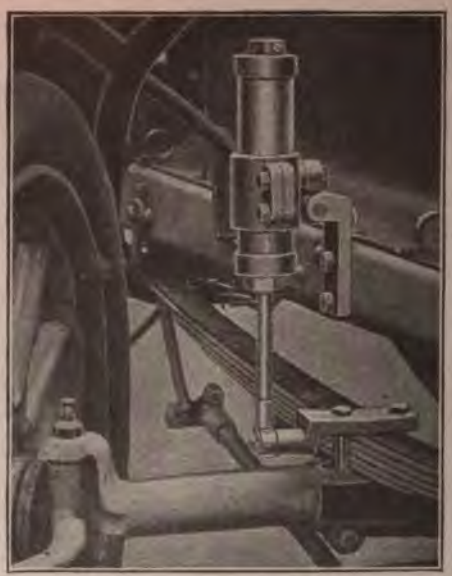

Fig. 77. Air-Cusion Shock Absorber.

Much of the comfort of a vehicle depends upon the upholstering. Deep springs in the cushions and backs add greatly to the ease of riding. This is particularly true in going over gutters or water bars where stiff, firm backs, as found in many tonneaus, transmit to the rider severe jolts, which, if the backs are high, are felt as disagreeable jerks at the neck. For high speed, low backs are more comfortable because they permit the entire spinal column to yield instead of the neck only. Deep springs, however, ease such objectionable features greatly.

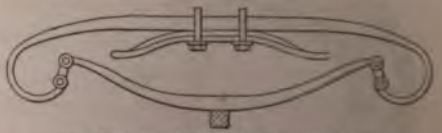

Fig. 78. Semi-Elliptic Rear Spring.

Since the auto is necessarily associated with oil, and is driven at high speeds in all weathers, the upholstering is best of leather or pantasote, so that it may not absorb oil nor dirt nor be soaked and damaged by water.

BEARINGS.

Auto bearings are in general of three kinds, plain, ball and roller. The plain or common carriage bearing gives good satisfac-

tion if frequently oiled and is of low first cost and needs few repairs. Rear axles which revolve are frequently mounted in plain bearings, usually of bronze or babbitt, with equally good results.

Fig. 79. Spiral Equalizing Spring.

For light vehicles, particularly with small power, as the light steam and electric carriages, ball bearings are quite common. The small area of the ball races requires that the balls, cups and cones be extremely hard in order to give service, and a broken ball frequently damages the bearing. The operator should listen for grinding or squeaking in the ball bearings and stop and remove the broken ball before further damage is done. For heavier loads, roller bearings are common. These are of several varieties, one well known form employing flexible rollers made by rolling a strip of metal into a spiral. The rollers are usually guided by cages to keep them parallel, and if not so guided should be quite short, preferably of a length not greater than their diameter. Rollers are usually

Fig. 80. Ball Bearing.

Fig. 81. Annular Ball Bearing.

hardened and ground. Conical rollers, also held in cages, are much used and are particularly adapted for places where the strain comes in various directions, as in the hubs of wheels. Ball or roller

bearings are much used to receive the thrust of bevel gears or friction disks.

Fig. 82. Plain, Flexible, and Conical Roller Bearings.

LAMPS.

The law in most places requires autos to carry lamps, although other vehicles do not as a rule carry them and cannot be seen by the auto driver unless he is provided with a searchlight able to light the road a great distance ahead. Without this assistance he may be unaware that a scary horse is doing damage and therefore unable to stop or govern himself accordingly. The searchlight throws a powerful beam which blinds the horse driver and renders him likely to leave the road. The safest arrangement is for all vehicles to carry a light on dark roads in order that each driver may be aware of the presence of the other.

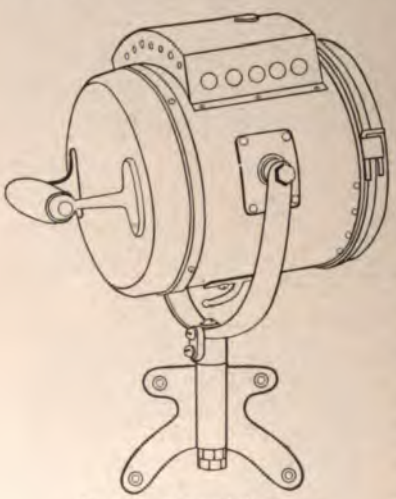

Fig. 83. Automobile Lamp.

OPERATION.

The operation of a vehicle depends much upon its particular design and information is usually supplied by the maker. In general, it is necessary to turn on the electric current, the liquid fuel, open the throttle, and turn the starting crank. After the motor

LIMOUSINE TYPE OF AUTOMOBILE, 1906 MODEL
The Winton Motor Carriage Co.

starts, adjust the gasolene to give best results, throttle the motor to suit, and set the low clutch gently. This throws a load on the the motor, to overcome which the throttle should be opened correspondingly. As the vehicle starts, feel of the steering to know that the vehicle is under control. As the speed increases change to a higher gear, the object of the skilled driver being to use the high gear as much as possible, in order that the motor may make as few revolutions per mile as may be, thus saving fuel and wear. In no event should the motor be choked down till it is jerky or liable to stop, for this may result in a stop in front of a train or in some similar dangerous and undesirable place.

The brake should be tested at the first opportunity and particularly before starting down a steep hill, so that it may be known to be in perfect order, for next to the ability to go, is the ability to control and stop. If the brake is faulty, the vehicle may be stopped by stopping the motor with the low speed clutch engaged and the clutch may also be used as a brake either instead of the regular brake or in conjunction with it on hills, thus forming a second brake, and one that is usually in order, as proved by the ability to climb hills. The low clutch is very effective and subjects the vehicle to a decided strain on which account it should be applied gently lest a chain be broken or gears stripped. In such an event the vehicle should be turned crosswise the road into the bank if circumstances permit. If the speed is too fast and the road is clear, and straight, the bottom of a hill may be safely reached but this dangerous chance should never be attempted except as a last resort. A properly powered vehicle will climb hills with little loss of time, so there is no need to rush down hill at a dangerous rate or with the vehicle beyond control.

The operator should learn to recognize by ear the proper running of all parts of the vehicle and recognize instantly any deviation therefrom. He should also recognize by the way the vehicle starts or coasts whether it runs freely or not, and by the feel whether a tire is flat or not. Lack of lubrication in the engine or vehicle adds much to the labor and expense and should be sought for and remedied. A weak spark causes a weak engine and signifies that either the batteries need renewal, the generator brushes need cleaning, the driving device is not doing its duty, or the electrical wires and connections are at fault. An excess of lubricating

oil will sometimes coat the interior of the cylinder with carbon, which should be removed by scraping, the cylinder heads being taken out for this purpose. The mixture should be right and the proper proportion of gasolene vapor and air must be determined by adjustment and trial. Usually more is required on a dry day than on a wet day because on a wet day the water vapor displaces some of the oxygen, so that less gasolene can be burned. Too much fuel weakens the mixture and soots the plugs and walls.

The cooling devices should be watched that the fan does not stop nor the water tank get empty, although in either case the engine may be run a short distance without damage before it gets hot enough to destroy the lubrication. The gasolene tank and piping should be so simple that it can be easily watched, for a leak is not only wasteful, but dangerous, because of possible fire. The tank should never be exposed to heat or burning vapor and tanks containing pressure are inadvisable because of the more rapid leak in such cases. For cold weather or for starting, a gasolene of low specific gravity, numbered high on the Baumé scale, is best, but a heavier liquid will give more power per gallon. With a hot engine, kerosene can generally be used, a fact which will enable one sometimes to get home after finding the gasolene tank empty. **Take great care that the battery is never left on a closed circuit for this quickly destroys its efficiency.**

REVIEW QUESTIONS.

PRACTICAL TEST QUESTIONS.

In the foregoing sections of this Cyclopedia numerous illustrative examples are worked out in detail in order to show the application of the various methods and principles. Accompanying these are examples for practice which will aid the reader in fixing the principles in mind.

In the following pages are given a large number of test questions and problems which afford a valuable means of testing the reader's knowledge of the subjects treated. They will be found excellent practice for those preparing for College, Civil Service, or Engineer's License. In some cases numerical answers are given as a further aid in this work.

REVIEW QUESTIONS

ON THE SUBJECT OF

THEORY OF DYNAMO-ELECTRIC MACHINERY.

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1. State the distinction between a generator and a motor.

2. (*a*) What is the object of the commutator? (*b*) Of what does it consist?

3. Why is it necessary to laminate the core of an armature?

4. How is the number of ampere-turns of a coil carrying current obtained?

5. What different parts make up the magnetic circuit of a dynamo?

6. What is meant by the density of a magnetic field?

7. Suppose a conductor and magnetic field both to be horizontal and at right angles to each other, the direction of the field being away from the observer; if the conductor were moved upward across the field, would the direction of the current induced in the conductor be from left to right or from right to left?

8. What is meant by the building up of a machine?

9. State briefly what is meant by hysteresis.

10. What do the electrical and stray power losses of a dynamo include?

11. (*a*) What is the relation between the direction of a current in a conductor and the direction of its magnetic field? (*b*) Between the polarity of an electro-magnet and direction of current in its coil?

12. Of what does the armature consist?

13. How are the coils of an armature successively short-circuited when a machine is in operation?

14. Upon what three factors does the electro-motive force generated by a conductor moving in a magnetic field depend?

15. In calculating the voltage of a machine what several factors must be considered?

16. What disadvantages has the magneto-dynamo?

17. When a closed coil is moved in a magnetic field in such a manner that there is no change in the number of lines passing through it, why will no current flow?

18. How are the coils connected to the commutator bars in a ring winding?

19. What opposes the free rotation of the armature when a dynamo is under load?

20. Describe briefly how the magnetization of an iron core increases as the ampere-turns of a coil are increased.

21. When is a coil said to be in the neutral position?

22. (a) Why does a single coil rotating between the poles of a magnet give a pulsating current? (b) State briefly how the pulsating current in the coils of a dynamo is made to give a current of uniform strength in the external circuit.

23. (a) Describe the difference between closed coil and open coil windings. (b) Between ring and drum windings.

24. Why is it that brushes of drum-wound machines are placed opposite the poles instead of between them as in ring-wound machines?

25. State the different causes which distort the field of a dynamo.

26. Why is it necessary to shift the position of the brushes when the load on a dynamo changes?

27. In the drum winding why is it necessary to have the forward and return portions of a coil under poles of opposite polarity?

28. What are the disadvantages of the series dynamo?

29. State the difference in construction between a series and shunt dynamo.

30. Describe the field connections of a compound-wound machine.

REVIEW QUESTIONS

ON THE SUBJECT OF

DIRECT CURRENT DYNAMOS.

1. Explain briefly the two different methods of distributing electrical power.

2. (*a*) Why does the series characteristic curve bend over and the voltage begin to decrease when the current is large? (*b*) Explain why the E. M. F. of a series dynamo decreases very rapidly from about two-thirds its maximum value upon decreasing the current. (*c*) Draw a diagram of the circuit of a series dynamo.

3. (*a*) Why is the voltage of a shunt dynamo at its maximum an open circuit? (*b*) Why does the voltage of a shunt dynamo decrease when the load is increased? (*c*) Draw a diagram of the circuit of a shunt dynamo.

4. (*a*) What is the general form of the characteristic of a compound dynamo? (*b*) What is the difference between a long shunt compound-wound dynamo and a short shunt compound-wound dynamo? (*c*) Draw a diagram of the circuit of a short shunt compound machine.

5. What values of E. M. F. and current are used in plotting the external, internal and total characteristics of the shunt dynamo?

6. How does the construction of shunt coils differ from that of series coils?

7. (*a*) Why does sparking occur if the position of the brushes is such that the short-circuited coils generate no E. M. F.? (*b*) What is the correct position of the brushes for sparkless running?

8. Why should not the current pass through the springs which are used to give the brushes proper pressure upon the commutator?

9. Explain why armatures need to be very carefully balanced.

10. Give the advantages of carbon brushes, and state why they are especially useful for high potential machines.

11. Explain why the resistance of the field coils of a shunt dynamo is calculated so low as to require a resistance rheostat to be placed in series with it.

12. What are the general tests which should be made upon a dynamo?

13. (*a*) Name the best conductors of magnetism. (*b*) How does the reluctivity of air compare with that of copper, brass, wood, etc.?

14. Upon what does the value of the magnetic flux in a magnetic circuit depend?

15. How does the residual magnetism of a dynamo affect the characteristic curve?

16. (*a*) What features are important in the construction of a good commutator? (*b*) How should a commutator be cared for in order to secure good running?

17. Name the precautions that should be taken when installing dynamos.

18. Referring to the electric circuit we have the terms — electric flux, electromotive force and resistance. What are the corresponding terms for the magnetic circuit?

19. What are the causes of sparking at the commutator?

20. How does a ring-wound armature differ from a drum-wound armature?

21. (*a*) Explain the effect of the series coil of a compound dynamo. (*b*) Explain why both shunt and series coils are required to make a dynamo self-regulating. (*c*) What is the effect if the series coil does not have enough turns? (*d*) What is the effect if the series coil has too many turns?

22. State the special advantages of a toothed armature core.

23. (*a*) Name the magnetic density per square inch usually allowed for field magnets of cast iron. (*b*) Of wrought iron (*c*) Of cast steel.

24. (*a*) What are horse-power curves? (*b*) What are resistance lines?

REVIEW QUESTIONS

ON THE SUBJECT OF

TYPES OF DYNAMO-ELECTRIC MACHINERY:

(DIRECT CURRENT).

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1. Show in what points modern generators are superior to older types.

2. State briefly what part the spider of a modern generator plays in the performance of the machine.

3. What is meant by a "generator of the engine type"?

4. What do you understand by an "iron-clad" armature?

5. Mention five different methods by which generators are driven.

6. What were the disadvantages of binding wires as applied to armatures, and by what means have they been dispensed with in modern generators?

7. Would you select an enclosed or open type of motor for operating a printing press which runs practically without intermission? State the reasons for your choice.

8. Discuss the advantages and disadvantages of direct-driven generators as compared with indirect-driven generators.

9. In modern machines of large size the outer yoke or frame is often stiffened by flanges. As the yoke is not subjected to outside mechanical strains, why is it necessary to stiffen it?

10. Describe different methods by which the armature may be removed from large size generators.

11. Describe the operation of the equalizer rings.

12. Describe briefly the improvements that have been made in the wearing qualities of modern commutators.

13. State what you consider to be good practice in deter-

mining current density for brushes of a low potential direct current generator.

14. State what you judge to be good practice in insulating armature coils.

15. Why should the efficiency of a 1000 K. W. generator remain high at low load while in the case of a 1 K. W. generator such results would not be expected?

16. What are the disadvantages of shafting as necessitated by indirect motor driving?

17. State why an "outboard" bearing is necessary in large belt-driven generators.

18. Show how a generator shaft is kept lubricated.

19. Why is a slow-speed motor preferred for general use in manufacturing plants?

20. In engine-type and direct-driven generators how is uniformity of rotation maintained?

21. Describe the dynamotor.

22. What do you consider to be good practice in calculating amperes per square inch of cross-section of conductor in armature coils for well-ventilated slow-speed engine-type generators? How many amperes would you permit an insulated armature conductor of bar shape, one-quarter inch thick and two inches wide, to carry?

23. In the Westinghouse arc lighting generator why should a separate exciter be recommended?

24. Indicate the present tendency in designing direct current motors, and state the advantages of connecting the motor directly to the machinery which it operates.

25. Give the essential features of a generating set for use on shipboard.

26. Discuss the various considerations that enter into the problem of equipping a manufacturing plant with motors.

27. By what means has it been made possible to use the electric motor in exposed positions and dust-loaded air?

28. What is good practice in allowing overload capacity in a railway motor?

29. Do you understand that slow-speed motors for a given output are heavier than high-speed motors, and if so, why?

REVIEW QUESTIONS

ON THE SUBJECT OF

DIRECT CURRENT MOTORS.

1. State briefly the fundamental principle of a motor.

2. Upon what does the speed of a motor depend?

3. The armature resistance of a motor is .6 ohm and the E. M. F. applied at the brushes is 120 volts. When the counter E. M. F. is 82 volts, what current passes in the armature?

Ans. 63.+ amperes.

4. Explain why the speed of a series motor on a constant potential circuit increases when the load is removed.

5. What are the different ways of reversing the direction of rotation of motors?

6. If the output of a motor is 60 horse-power and the armature makes 490 revolutions per minute, what is the torque?

Ans. 643.+ foot-pounds.

7. Why is it necessary to cut out the starting resistance of a motor in order that it may be brought up to speed?

8. In what direction will the armature of a shunt generator rotate when run as a motor compared with the direction of rotation when run as a generator? Explain.

9. Explain briefly the different methods used to vary the speed of shunt motors.

10. A shunt motor on a 230 volt circuit takes 55 amperes at full load, the speed being 760 revolutions per minute. What resistance is it necessary to insert in the armature circuit in order to have the motor run at $\frac{2}{3}$ speed when the torque is $\frac{1}{2}$ that at full load? Ans. 2.8 ohms (approx.).

11. In stopping a shunt motor why should the main switch be opened *before* the armature circuit is broken?

12. What are the advantages and disadvantages of series motors?

13. The current in the armature of a shunt motor is 30 amperes and the E. M. F. at the brushes is 220 volts. If the armature resistance is .8 ohm, what is the counter E. M. F.? Ans. 196 volts

14. What is the difference between the electrical and gross efficiency of a motor?

15. What is the commercial efficiency of a 500 volt motor which takes a current of 120 amperes, the output being 71.6 horse-power? Ans. 89 %.

16. Explain how a differential compound motor gives a constant speed.

17. Why is it unnecessary to use a starting resistance for series motors on constant current circuits?

18. The torque exerted by a 35 horse-power motor is 335 pound feet. What number of revolutions per minute does it make? Ans. 549 r. p. m. (approx.).

19. In the preceding example what is the pull in pounds at the circumference of the pulley if the pulley is 20 inches in diameter? Ans. 402 pounds.

20. What is the great objection to reversing a motor while running?

21. Shunt motors have what great advantage?

22. Explain how by overwinding the field coils of a series motor, nearly constant speed may be obtained with varying load.

23. How may the necessity of shifting the brushes of a motor with change of load be largely prevented?

24. In what cases may series motors be used to advantage?

25. (*a*) What is a cumulative compound motor? (*b*) State its advantages.

26. Why are motors but little used on constant current circuits?

27. The differential motor has what serious disadvantage?

28. The counter E. M. F. of a shunt motor on constant potential mains has what value when the output is a maximum?

29. A motor is to be installed that is to be frequently stopped and started under a heavy load, and must have a nearly constant speed. What kind of a motor should be used?

30. It is desired to run a compound generator as a motor and in the same direction as when run as a generator. (*a*) What connections if any must be changed? (*b*) Will it be necessary to move the brushes?

REVIEW QUESTIONS

ON THE SUBJECT OF

STORAGE BATTERIES.

1. What is the lowest value to which a lead battery should be discharged?

2. What means may be employed to make up for the drop in potential of storage batteries during discharge?

3. What causes sulphating?

4. What plate of a storage battery is the positive?

5. Describe the several indications by which the amount of charge in a storage battery can be determined.

6. How is the capacity of a storage battery usually expressed?

7. What is an electrolyte?

8. What is meant by floating battery, and when is it applicable?

9. How must a storage battery room be arranged?

10. What causes buckling?

11. Why are there always more negative plates than positive plates in a storage battery?

12. Give several applications of storage batteries.

13. When a storage battery is charged what is found on the positive plate and what is found on the negative plate, and what occurs when the cell is discharged?

14. What is the maximum voltage obtainable from a lead storage cell?

15. How may sulphating and buckling be prevented?

16. How would you put a battery out of commission for a long period, and how would you place it in service again?

17. What is the difference in construction between Faure and Planté plates?

18. What is the essential difference between a primary and storage battery?

19. What instruments are required on a storage battery switchboard, and how are they connected?

20. If a battery be discharged at a greater rate than its normal, how does it temporarily affect the capacity of the cell?

21. What impurities in the electrolyte must be guarded against, how is their presence caused, and how determined?

22. Which type of cell has the larger storage capacity per lb. of cell, and why; the Faure or Planté?

23. Why is the storage battery useful in electrical laboratories?

24. What is the specific gravity of the electrolyte of a lead cell when fully charged, and about what when discharged?

25. What is the constant current booster system, and where is it most applicable?

REVIEW QUESTIONS

ON THE SUBJECT OF

AUTOMOBILES

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1. What is the function of mufflers, and what troubles are they liable to develop?

2. Describe the methods of cylinder cooling in general use. What is the most economical temperature for the cylinders of a gasolene motor?

3. Describe the sliding gear transmission.

4. What is the difference in the action of the block, roller, and self-adjusting sprocket chains?

5 If the brake refuses to act what alternative remains to stop the machine?

6. How is the flexibility of the propeller shaft secured?

7. What forms of cooling surfaces are commonly used for air-cooled cylinders?

8. Describe the three forms of ignition.

9. Describe the steps to be taken in the operation of an automobile, and state what parts of the machine require special attention.

10. Name the three general classes of automobiles.

11. Explain the difference between 2-cycle and 4-cycle motors.

12 Describe the multiple disc clutch.

13. What is the effect on the motor of too rich gas?

14. Describe the usual method of steering an automobile.

15. How is the circulation of air maintained for air-cooling?

16. How is a sprag used?

17. Describe the white steam generator. How does it differ from an ordinary boiler?

18. What is the relative position of the clutch in the transmission system?

19. What causes premature ignition, and what is its effect?

20. What are the most common chain troubles, and how are they remedied?

21. Describe the devices used to supplement the springs of automobiles.

22. Describe four forms of friction drives.

23. What changes in automobile design are suggested by American road conditions?

24. What are the essential features of the rear axle?

25. What operations may be controlled by the steering wheel?

26. What kinds of bearings are in general use? Give the relative advantages of each kind.

27. How can the compression be tested?

28. Describe the methods used for varying the proportion of gasolene and air in different carburettors.

29. Describe the types of pumps used for water circulation.

30. Describe each of the essential parts of a gasolene motor.

31. What is the object of the differential gear, and where is it used?

32. What type of wheel is commonly used for automobiles? Describe its construction.

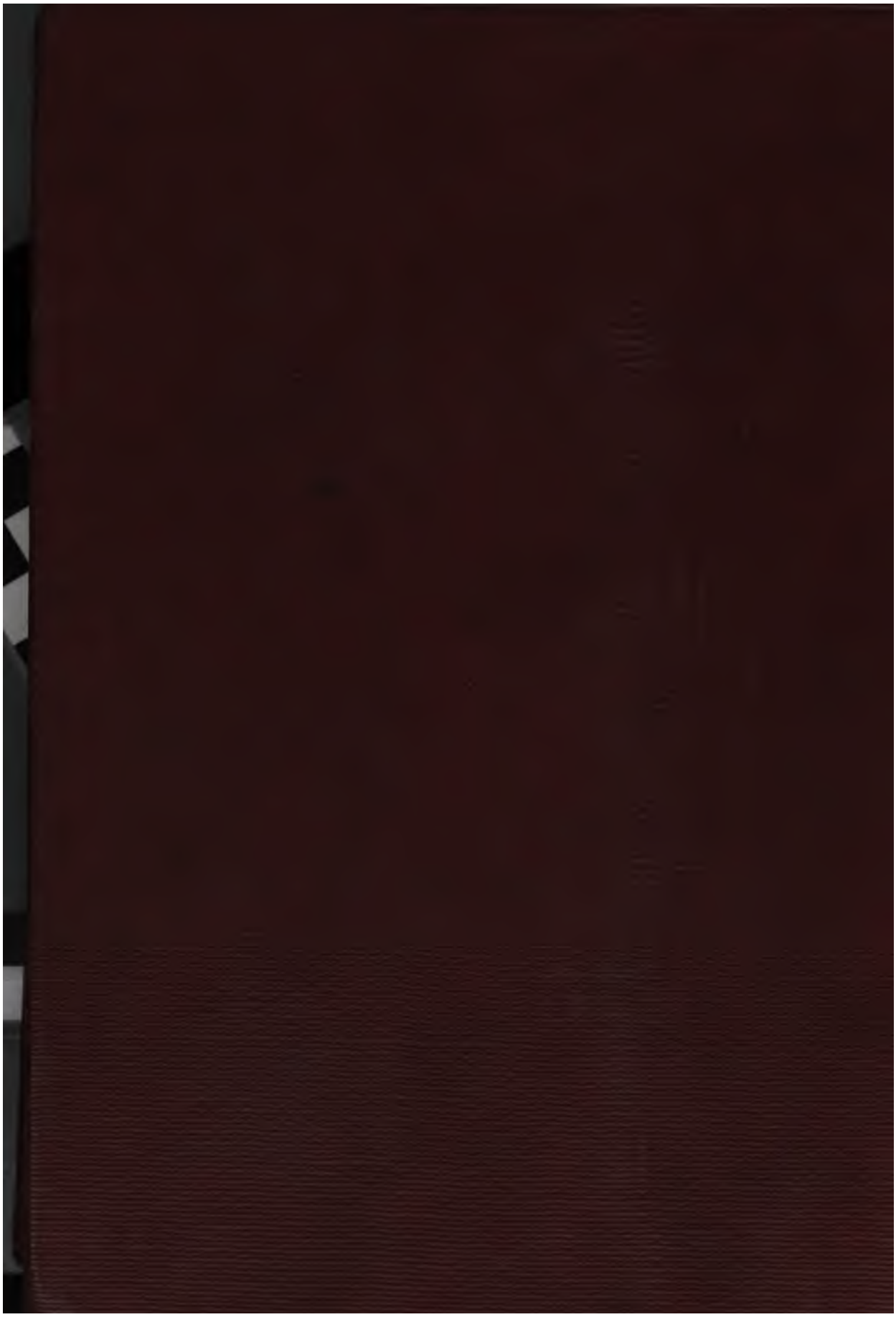
33. What considerations determine the location of the engine on the chassis?

34. What is the function of planetary gears, and how do they operate?

35. What is the function of radius rods, and where should they be located?

36. What is the most common form of brake for automobiles?

37. What is the most desirable method of vehicle control?

38. What is the general arrangement of the propeller shaft transmission?

39. What are the three methods of fastening pneumatic tires to the wheel rims?